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0.1 WAVENUMBER SPECTRAL MEASUREMENTS IN THE REGION FROM 2050 TO--ETC(U)
DEC 78 M J PERSKY N60530-78-C-0272
UNCLASSIFIED BEI-78-761 NL

1 OF 2
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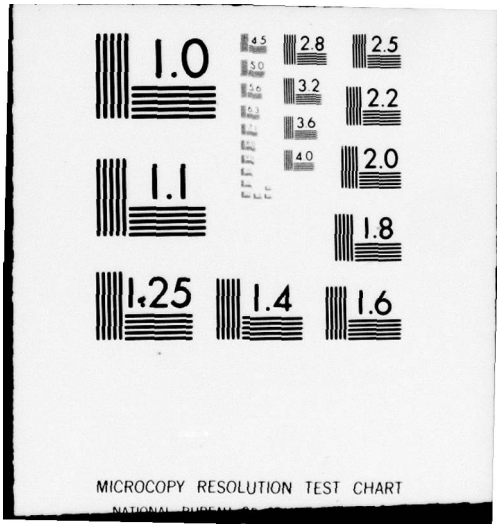
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(14) BEI-78-761

(6) 8.1 Wavenumber Spectral Measurements In the Region From 2050 to 2410 Wavenumbers of a Static, Experimental Rocket Motor At Three Pressure Altitudes,

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PREFACE

The work reported herein was performed under Contract N60530-78-C-0272. The Technical Monitor was S. T. Smith, NWC Code 39403. The assistance of Capt. William Rothschild and Mr. Dale Fink of the Armament Development and Test Center, Eglin AFB, Florida is gratefully acknowledged.

1. INTRODUCTION AND SUMMARY

Development of military infrared systems dictates a need for high resolution, infrared spectral data on exhaust plume radiation as a function of altitude and spatial position. To satisfy this need, ~~Block Engineering, Inc. performed~~ were performed high resolution spectral measurements on a small, experimental rocket motor at the Electro-Optical Facility, Air Force Armament Laboratory, Eglin AFB, Florida. This is the Final Report for that effort.

The motor was operated statically in an altitude chamber, at simulated pressure altitudes of sea level, 4.57 km and 12.19 km. The spectrometer was oriented at 90 degrees to the exhaust, viewing the plume through a calcium fluoride window. The motor was translated axially such that the observed spatial element for a given run was centered at either 5, 15, 25, 35 or 45 cm from the exit plane. The spatial element was a nominal 10 cm in diameter.

The spectrometer was of the Fourier transform, interferometric type. The spectral range over which meaningful data were obtained was 2050 to 2410 wavenumbers and the spectral resolution was a nominal 0.1 wavenumber.

All measurements were successfully obtained yielding the significant spectroscopic data reported herein.

2. DATA ACQUISITION

2.1 INSTRUMENTATION

A Block Engineering, Fourier transform, interferometer spectrometer was used to obtain the plume data. Its specifications are given in Table 2.1-I. This instrument, a Model 496, features 0.1 wavenumber spectral resolution and an InSb short wavelength detector.

The spectrometer utilizes the Michelson optical system. It consists of two physically separate but electronically connected components: the optical head and the electronic console. The optical head contains the signal interferometer optics (beamsplitter, compensator, fixed and moving mirrors); a nominal 4 to 5 micron bandpass filter; the detector preamplifer; and the moving mirror drive system which includes the mirror position monitor (reference interferometer).

The mirror position monitor consists of a second interferometric optical system comprised of a beamsplitter; fixed mirror; tungsten lamp and helium-neon laser sources and a moving mirror rigidly linked to the moving mirror of the signal interferometer. The tungsten lamp produces a fiducial mark at the beginning of each scan; the laser produces a reference sine wave used to trigger the computer interface during data collection/processing.

TABLE 2.1-I

SPECTROMETER SPECIFICATIONS

BEI MODEL	496
SPECTRAL REGION (For These Data)	2050-2410 cm^{-1}
RESOLUTION (Rayleigh Criterion @ 2000 cm^{-1})	0.09 cm^{-1}
FIELD OF VIEW (Response at 50% Maximum; Nominal Value)	22.2 mr (Circular)
MIRROR TRAVEL TIME	1300 msec.
OBSERVATION TIME (For These Data)	20.8 sec.
COLLECTOR DIAMETER	2.54 cm
RETARDATION (From Zero)	8.053 cm
APODIZATION (Applied During Data Processing)	Rectangular
EFFECTIVE REFERENCE FREQUENCY (Vacuum)	15,798.4 cm^{-1} (Vacuum)
NUMBER OF SAMPLE POINTS	32,000
SAMPLE FREQUENCY	3949.6 cm^{-1}
SENSITIVITY (τ=20.8 sec.; excluding plume noise)	0.7×10^{-11} watts/(cm^2-cm^{-1})

The electronics console contains the detector postamplifier, power supplies and the three operator control functions - amplifier gain, optical retardation and sample interval. A temperature control system maintains the optical head at a constant pre-set temperature.

The amplifier gain was changed from run to run to account for the wide variety of intensity levels including calibrations, backgrounds and plumes. The optical retardation remained constant at its maximum value of 8 cm. The sample interval divides the reference sine wave by four to satisfy the sampling criterion that the sampling optical frequency be twice the signal bandwidth while minimizing the number of sample points which must be computer processed.

An analog tape recorder (Hewlett-Packard 3960) was used to record the interferometer signal output and reference for later processing.

The optical head was mounted on a large optical bench located in front of a calcium fluoride viewing window in the side wall of the altitude chamber. A helium-neon alignment laser was used to establish a position reference for the translation of the motor. This laser was also used to verify the orthogonality between the interferometer and motor. The interferometer output signal resulting from this laser should be a sine wave with an amplitude constant over the entire length of the mirror motion. A pre-measurements test insured that this was indeed the case. The test was conducted with the 4 to 5 micron bandpass filter removed.

2.2 ON-SITE ACTIVITIES

The measurements were made during the period from September 21 to September 27, 1978. Motor specifics are presented in Table 2.2-II and run by run operating parameters are in Table 2.2-III.

TABLE 2.2-II

MOTOR SPECIFICS

Oxidizer/Fuel Ratio	4.5
Gaseous O_2 Flow Rate	4.1 grams/sec
RP1 Flow Rate	0.9 grams/sec
Chamber Pressure	40 psia
Throat Diameter	5.08 mm
Nozzle Length	4.95 mm
Exit Diameter	7.87 mm
Distance to Spectrometer	409 cm

TABLE 2.2-III

MOTOR OPERATING PARAMETERS

Spectrum No.	Altitude, Km	Spatial Position, cm*
1	0	45
2	4.57	45
3	12.19	45
4	0	35
5	4.57	35
6	12.19	35
7	0	25
8	4.57	25
9	12.19	25
10	0	15
11	4.57	15
12	12.19	15
13	0	5
14	4.57	5
15	12.19	5

* Axial distance from motor exit plane to spectrometer field of view center.

A major problem in obtaining the plume data was the presence of plume-induced noise. An initial series of measurements indicated that the plume turbulence was of sufficient magnitude that the resultant intensity modulation produced a significant noise component. To reduce this effect, several experiment changes were made. First, the normal broad band spectral response of approximately 1850 to 3300 wavenumbers was narrowed to the 2050 to 2550 wavenumber region of primary interest by use of an optical filter.* [1]

Additionally, the distance between interferometer and motor was enlarged from the initial 132 cm to the final distance of 409 cm - the maximum possible. This accomplished two things: a) the increased atmospheric absorption reduced the intensities of the modulating species and b) the larger observed area increased the spatial integration and reduced the modulation component which is highly local in the plume.

Otherwise, the measurements proceeded normally. In addition to the motor data, intensity and wavelength calibrations were recorded (See Section 2.3). Background measurements were made both prior to and after each engine run.

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* The data plots in this report were further limited to 2410 wavenumbers because of the lack of any spectral features between 2400 and 2550 wavenumbers.

1. Note that in Fourier transform spectroscopy, amplitude modulation occuring during the scan of the interferometer appears as spectral side bands. A full analysis is not possible here and the reader is referred to one of the many texts on this subject.

2.3 CALIBRATIONS

The system responsivity was measured using an extended, conical blackbody source located at the spectrometer aperture. The source was operated at 90°C and was used both at the beginning and at the end of the plume data taking.

The interferometer's self-radiation was measured using a hollow metal target filled with liquid nitrogen to reduce its surface temperature to approximately 77°K. At this temperature the surface provides negligible radiation. When placed at the entrance to the optical system, the recorded signal is the isolated result of radiation from elements within the optical system.

The optical frequency scale for the spectra is based on the 15,797 cm^{-1} (vacuum) emission line of a helium neon laser incorporated in the optical head. As the interferometer operates, a sync signal is generated by this laser. This sync signal is recorded in parallel with the interferogram and is used as the gating signal for the analog to digital converter employed in data processing. The effective optical frequency of this reference laser, as aligned in the interferometer, was calibrated using a second helium neon laser located at the motor. The specific line used is located at 2947.85 cm^{-1} (vacuum)[1].

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1. Pressley, R.J., Handbook of Lasers, Chemical Rubber Co., Cleveland, OH, 1971, pg. 207. The value for ν is given in air. The conversion to ν in vacuum used the index of refraction of air at STP from: Allen, C.W., "Astrophysical Quantities", University of London, The Athlone Press, 1963, Page 119.

The field of view was measured on-site with a point source blackbody located at the motor reference position. The distance to the source was 409 cm. The blackbody was operated at 900°C with an aperture of 0.050 inches and modulated at 5800 Hz. The blackbody was translated both horizontally and vertically and the signal output noted at each position. The results of this calibration are provided in Figure 2.3-1. The motor position for a typical set of runs is superimposed for illustration.

2.4 DATA PROCESSING

The data processing procedure was divided into eight sequential steps as follows:

Step 1 - Signal Digitization: The field recordings were reproduced by the Block Engineering FTS Data System for digitization and storage in a Data General Corp., NOVA 1200 computer.

Step 2 - Coherent addition: As the interferogram levels were constant with time, sixteen successive interferograms were coherently added in the computer resulting in an improvement in signal-to-noise over that of a single interferogram. This represents approximately twenty seconds observation time.

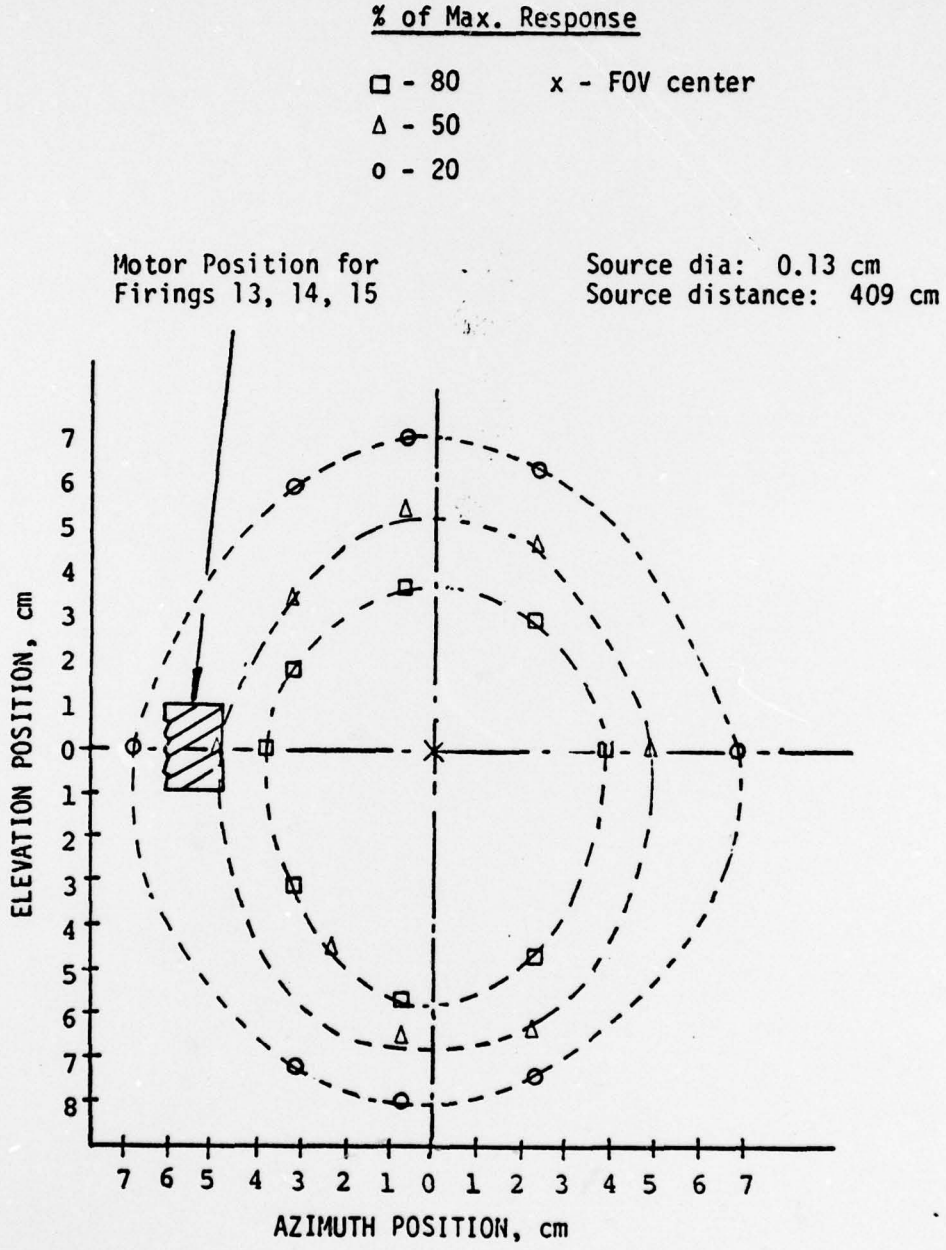
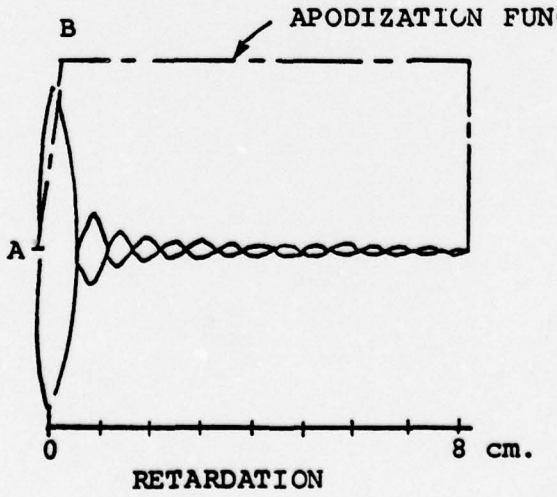


Figure 2.3-1. Spectrometer Field of View at Plume.

Step 3 - Spectrometer Self-Emission and Background Subtraction: The raw interferograms contain unwanted contributions from the spectrometer self-emission and background. These are eliminated by coherently subtracting a raw, coadded background interferogram obtained prior to motor firing number four. Review of all background runs indicated that this run was typical of all backgrounds. The resulting interferogram represents a signal due solely to the motor plume. For the blackbody calibrations and background run, a raw liquid nitrogen interferogram was subtracted from the raw blackbody interferogram to provide a blackbody (or background) alone interferogram.

Step 4 - Apodization: Prior to the computation of the transform, each interferogram was apodized by a nearly rectangular weighting function with the breakpoint (B) at twice the location of the peak signal in the interferogram.



The apodization from (A) to (B) is required because zero retardation has been purposefully located at one end of the interferogram to maximize the resolution capability of the interferometer.[2]

Step 5 - Perform Fourier Transform: A Phase corrected, amplitude Fourier transform is performed on the resulting interferogram using the Cooley-Tukey algorithm. This produces a relative amplitude spectrum of the motor plume emission.

Step 6 - Responsivity Correction: Dividing this spectrum by the calibrated system responsivity produces the spectrum of spectral power versus optical frequency. Further dividing this by the collector area yields the absolute spectrum in terms of the apparent spectral irradiance.

Step 7 - Atmospheric Transmission Calculation: A calculation of atmospheric transmittance for the 409 cm measurement distance was made using as input the AFGPL HITRAN computer tape. This tape contains a line-by-line listing of spectroscopic parameters for infrared-active molecules occurring naturally in the atmosphere. The parameters included in the computation for each line are: frequency, intensity, half-width, energy of the lower state of the transition, vibrational and rotational identifications of the upper and lower energy status, an isotopic identification and a molecular identification. The molecules included are: water vapor, carbon dioxide, ozone, nitrous oxide, carbon monoxide, methane, and oxygen.

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2. Mertz, L. "Transformations in Optics", John Wiley and Sons, New York 1965.

The atmospheric properties assumed for the calculation were: a) temperature = 72°F
b) relative humidity = 70%
c) pressure = 1 atmosphere

Step 8 - Archival Storage and Presentation: Each spectrum as well as the interferograms used were written on digital magnetic tape for archival storage to facilitate future reprocessing. Hard copy plots were also made for reporting purposes.

Two digital tapes for customer use were also prepared*. Tape 142 contains the final corrected data only, one plume spectrum per tape file plus individual files containing a representative background and an atmospheric transmittance spectrum. Each file contains a header providing run identification and the data itself in the form of apparent spectral irradiance.

Note that the beginning of each data file corresponds to 3949.60 wavenumbers; the end of each data file corresponds to 1974.80 wavenumbers.

Table 2.4-I lists the tape files, indicating the file for each spectrum. Note that files 5, 10 and 17 are void and should not be used.

Tape 176 contains the calculated atmospheric transmission.

* BEI Numbers 142 and 176.

TABLE 2.4-I

TAPE 142 - FILE LISTINGS

File		Identification
1	Motor Firing	#1
2	"	2
3	"	3
4	"	4
5	Void	
6	Motor Firing	6
7	"	7
8	"	8
9	"	9
10	Void	
11	Motor Firing	11
12	"	12
13	"	13
14	"	14
15	"	15
16	Background	(Pre-Motor Firing #4)
17	Void	
18	Motor Firing	5
19	"	10

TABLE 2.4-II

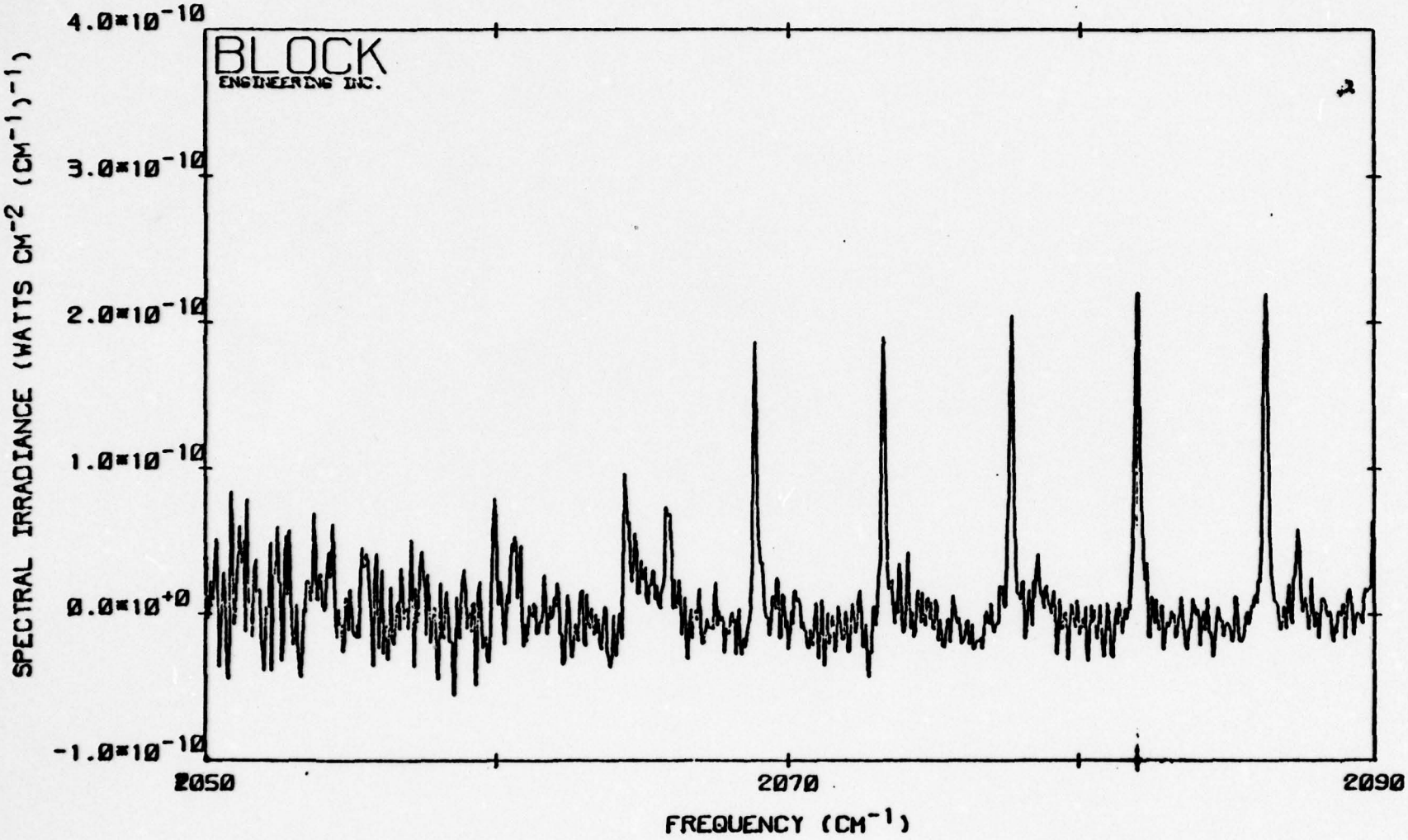
TAPE 176 - FILE LISTINGS

File	Size	Spectral Region	Identification
1	4K points	2050 - 2210 cm^{-1}	TR 1234B
2	1K points	2210 - 2250 cm^{-1}	TR 5B
3	"	2250 - 2290 cm^{-1}	TR 6A
4	"	2290 - 2330 cm^{-1}	TR 7A
5	"	2330 - 2370 cm^{-1}	TR 8A
6	"	2370 - 2410 cm^{-1}	TR 9A

3. DATA PLOTS

The seventeen spectral data sets processed are contained in this section. They are identified by the number located in the lower right hand corner preceded by the letters VF or HF. Note that nine separate plots are required for one complete spectrum.

No attempt has been made to analyze these data since this task will be performed by others. However, it is clear that the band center is more evident and additional CO lines appear as the pressure altitude decreases.



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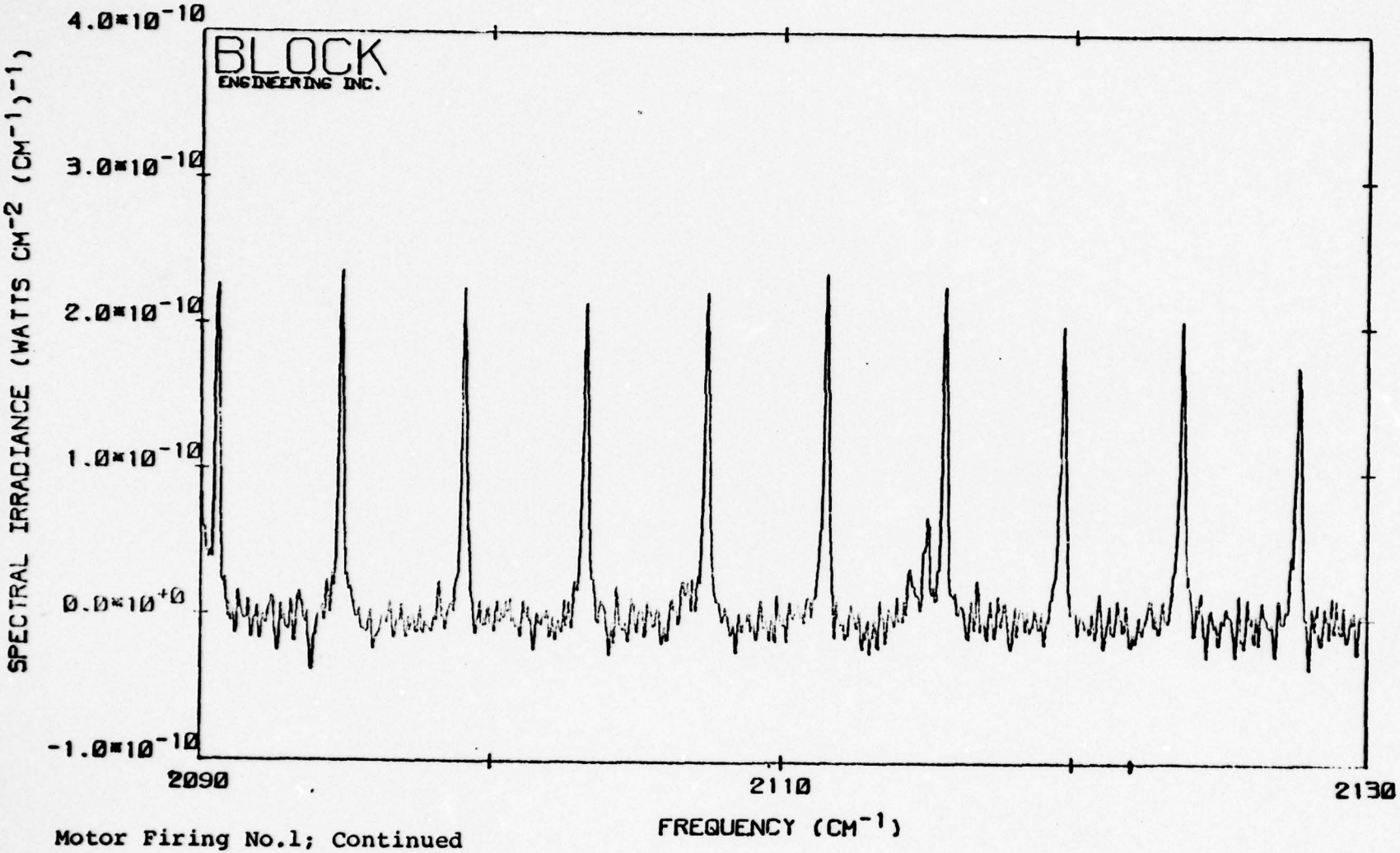

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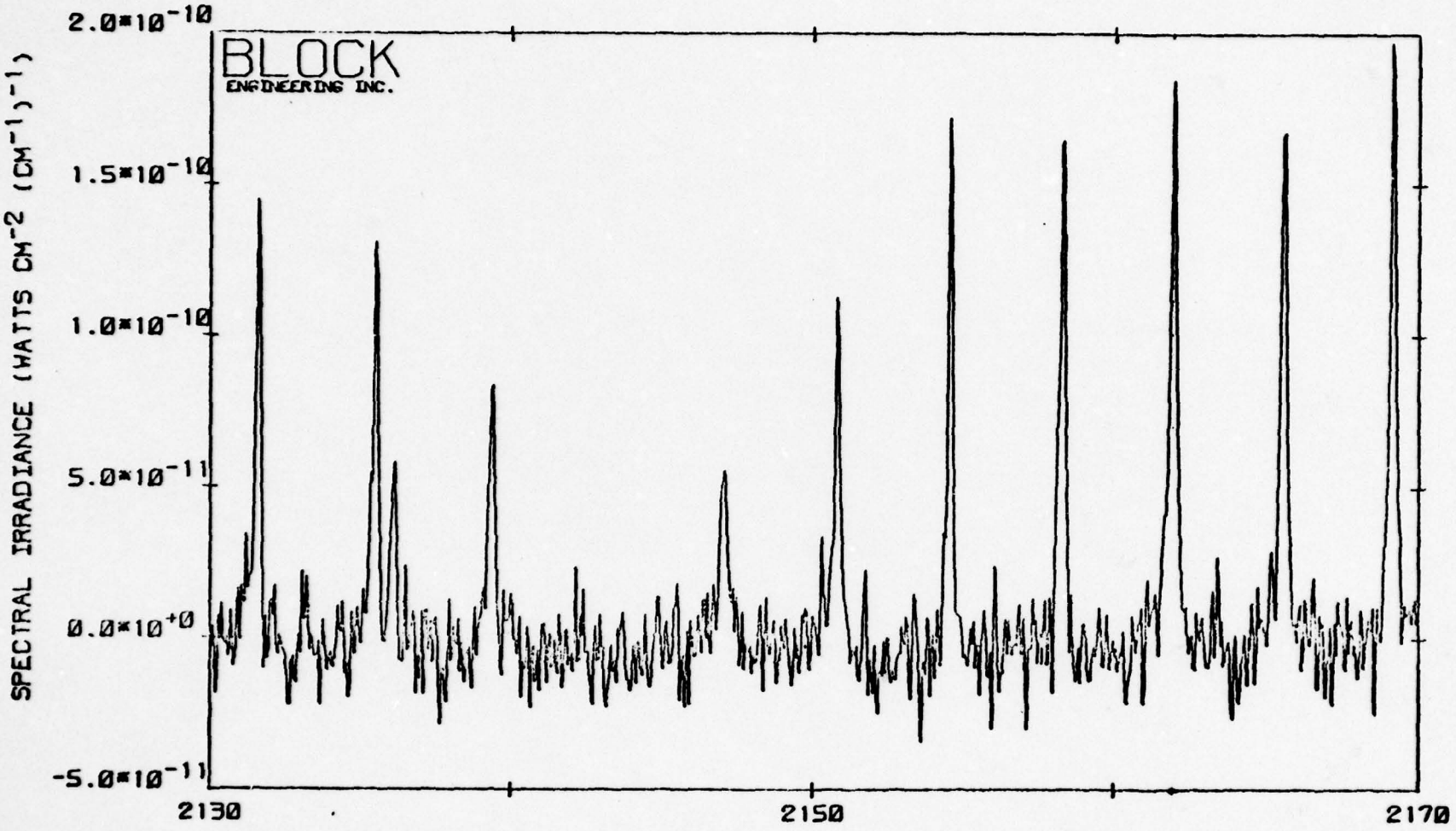

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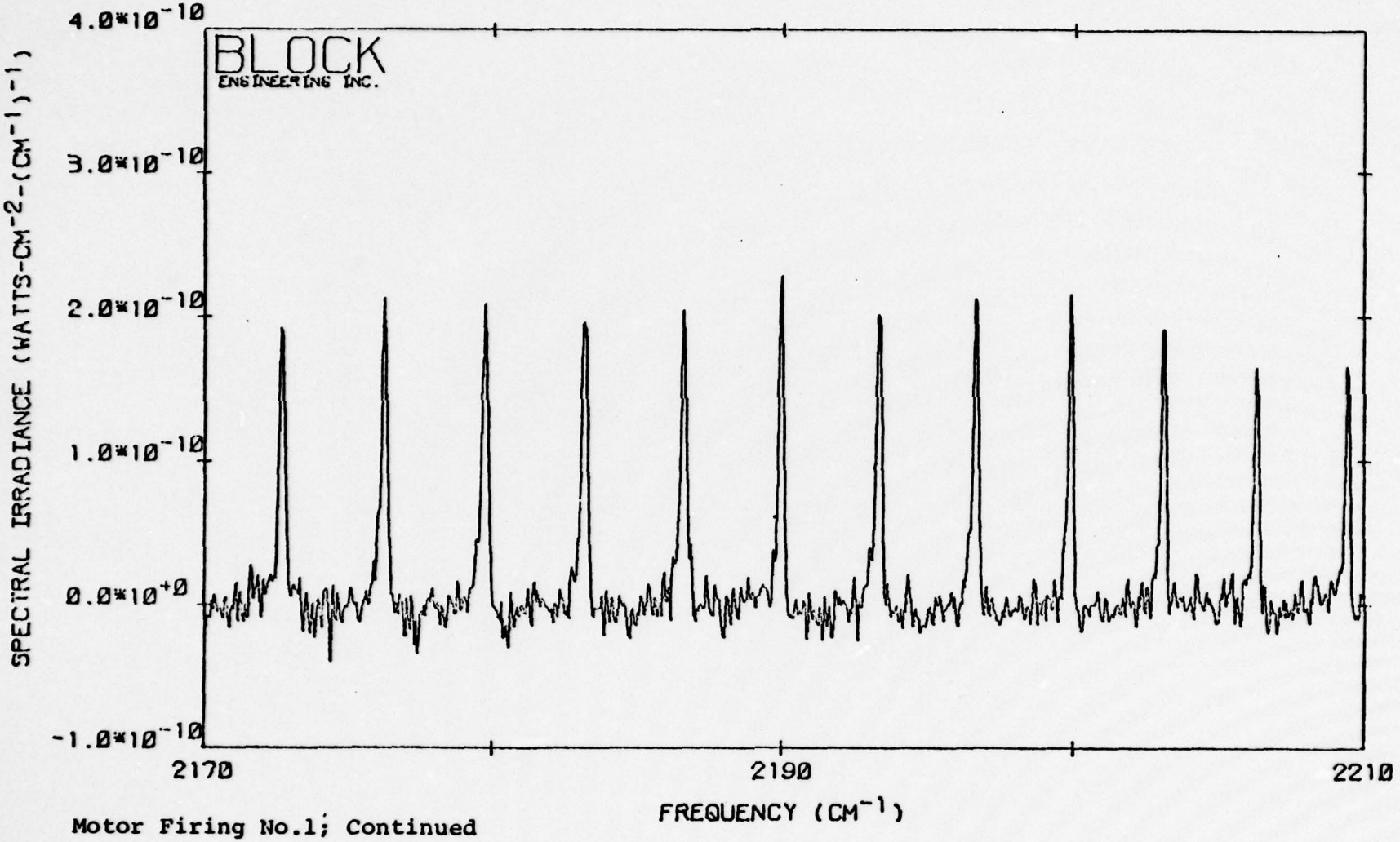

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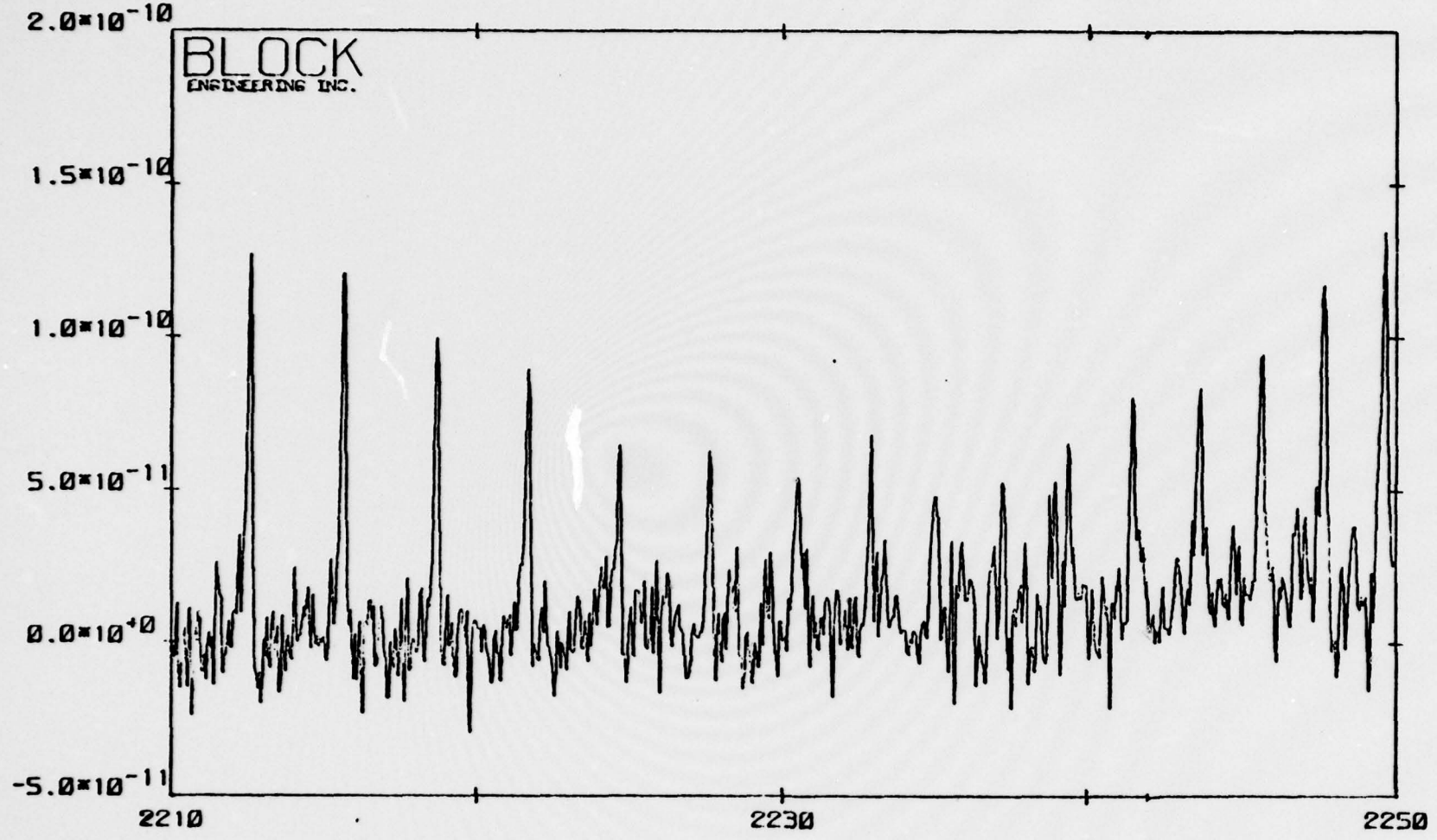

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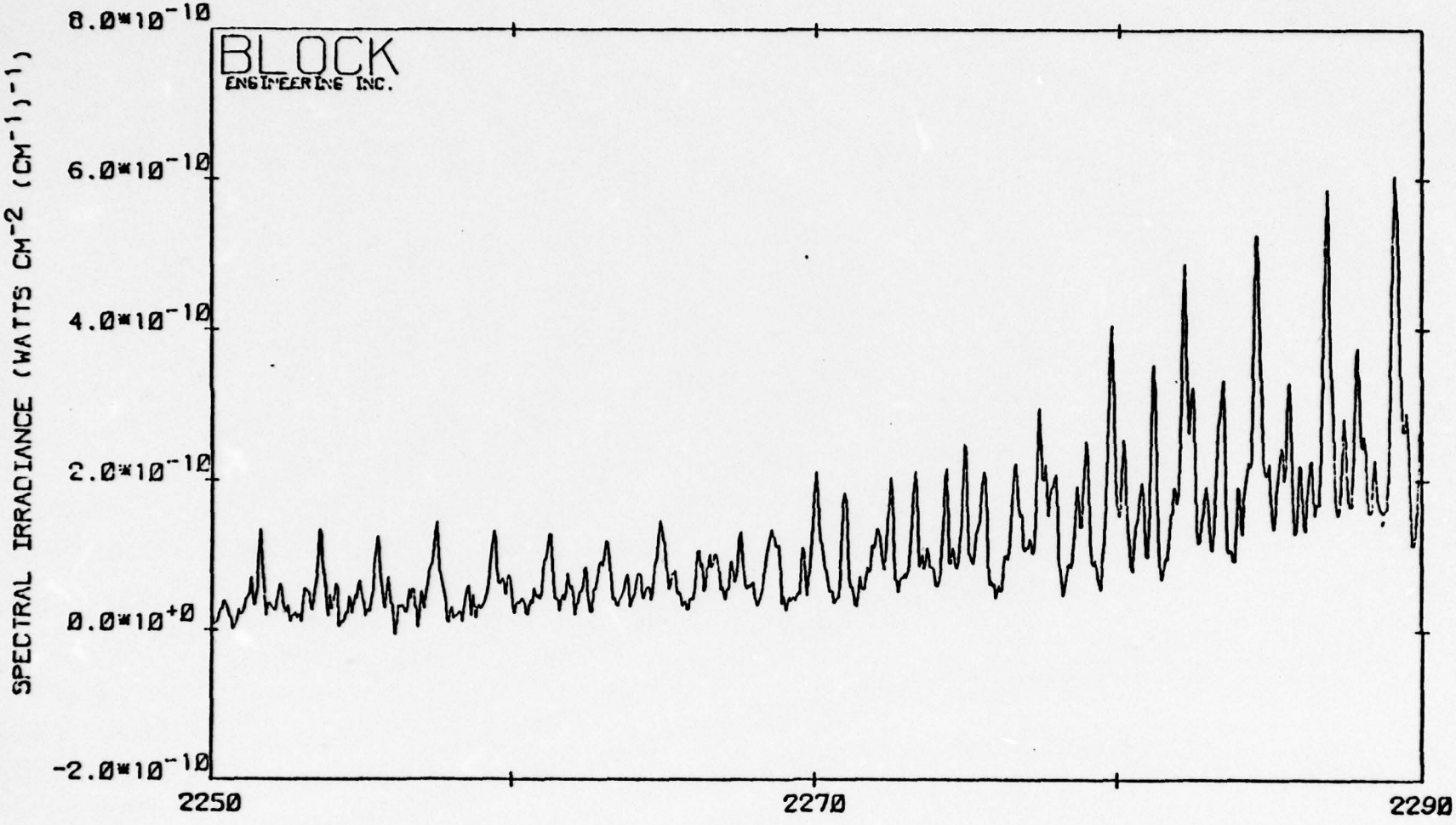

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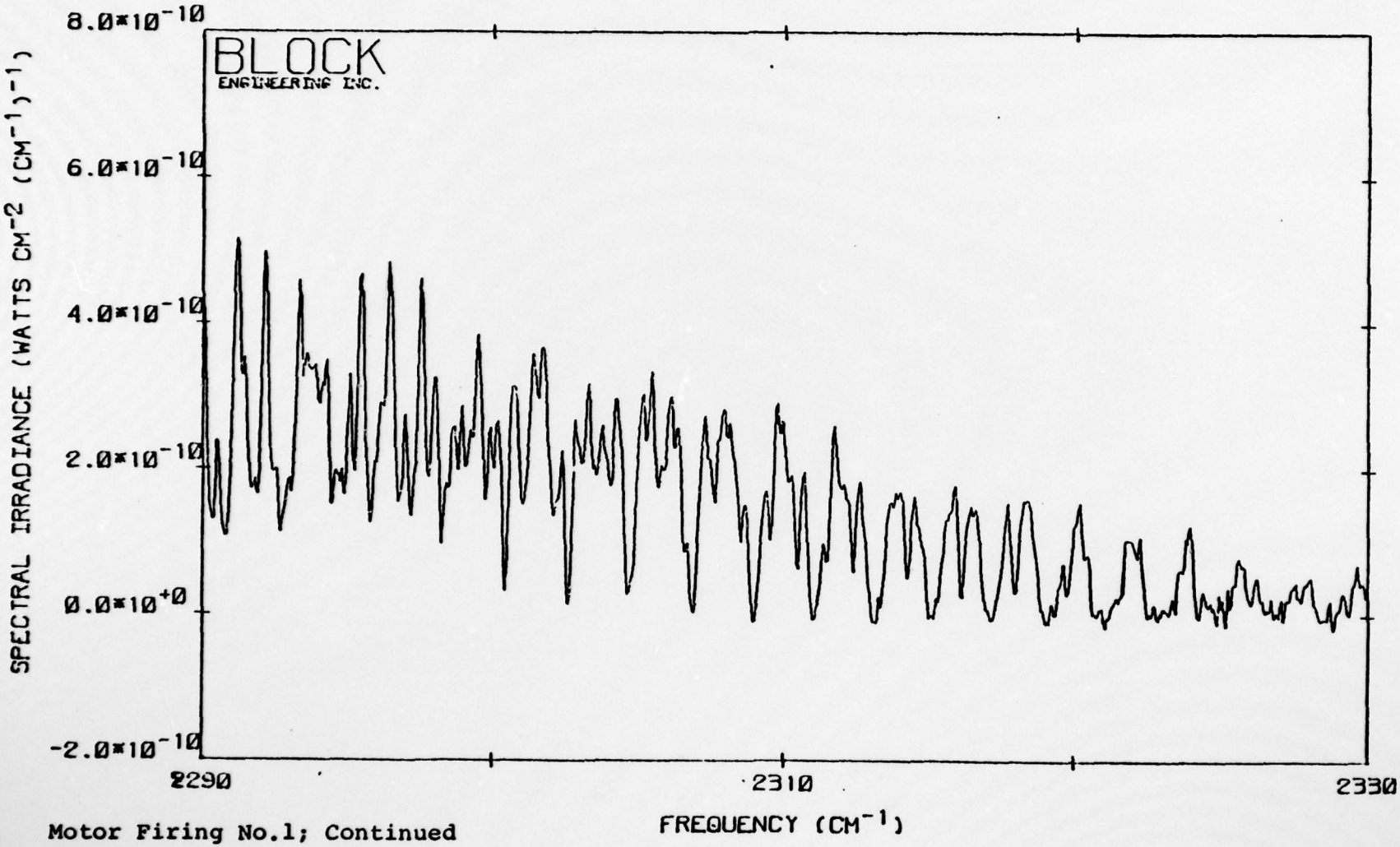

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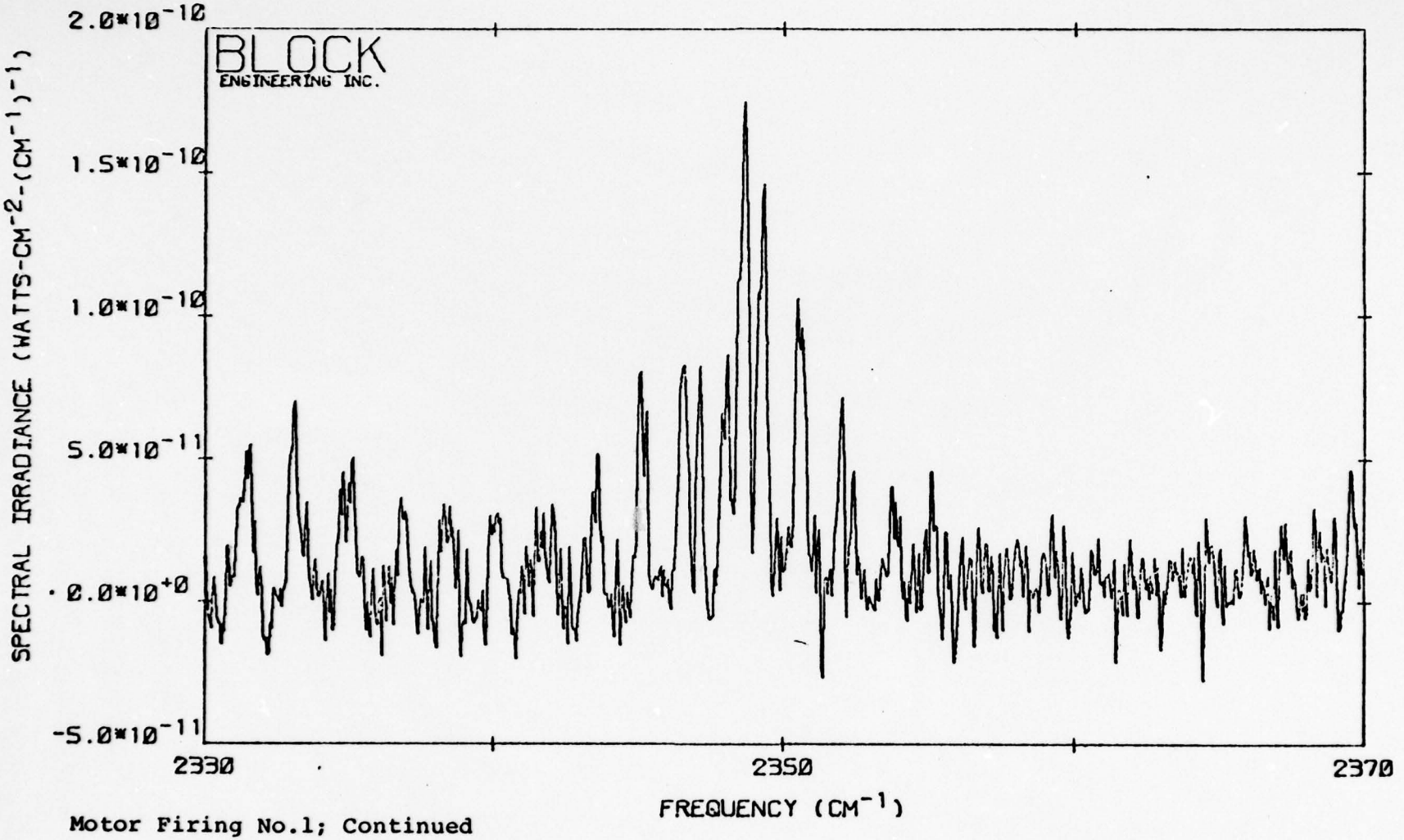

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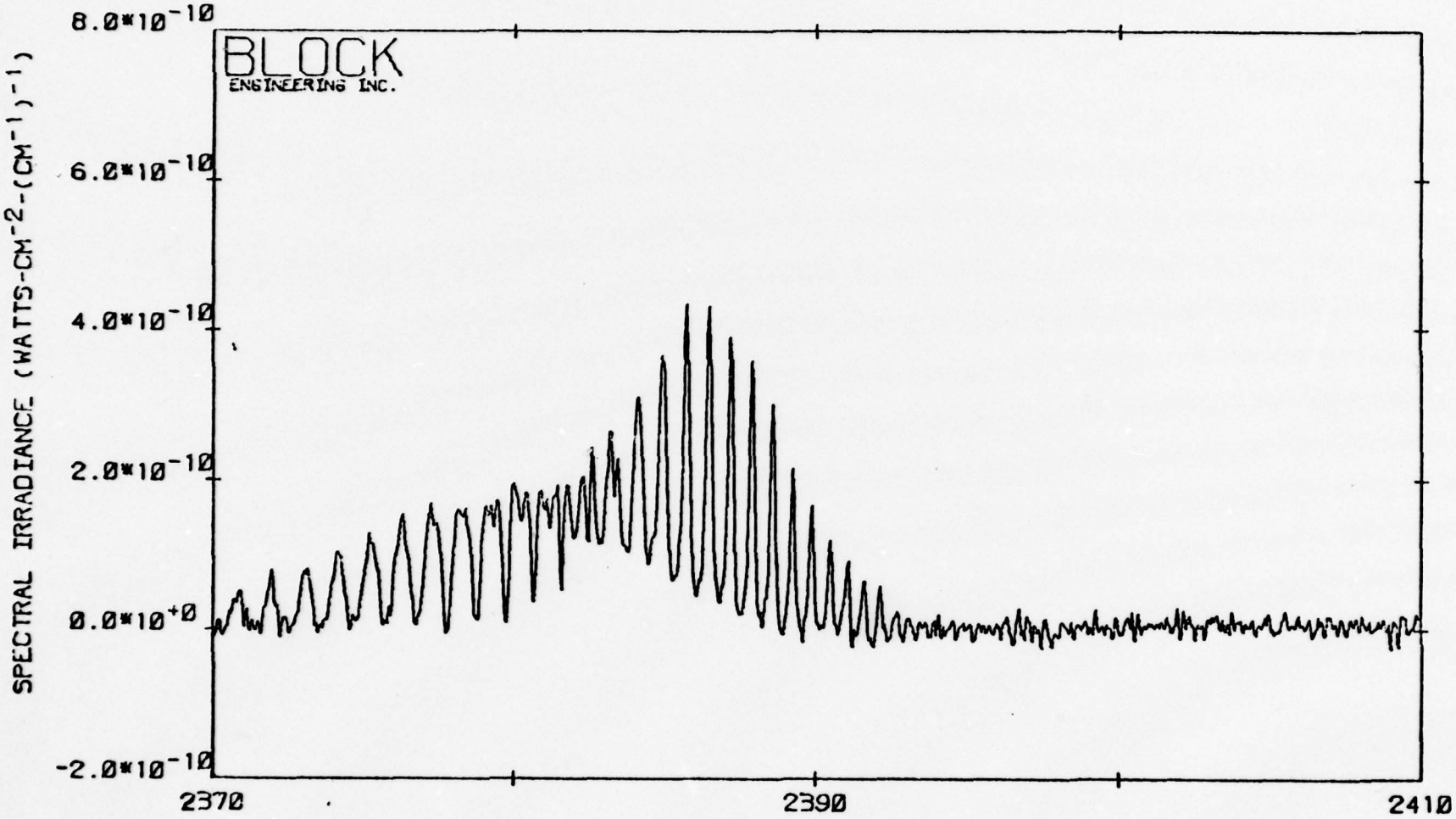

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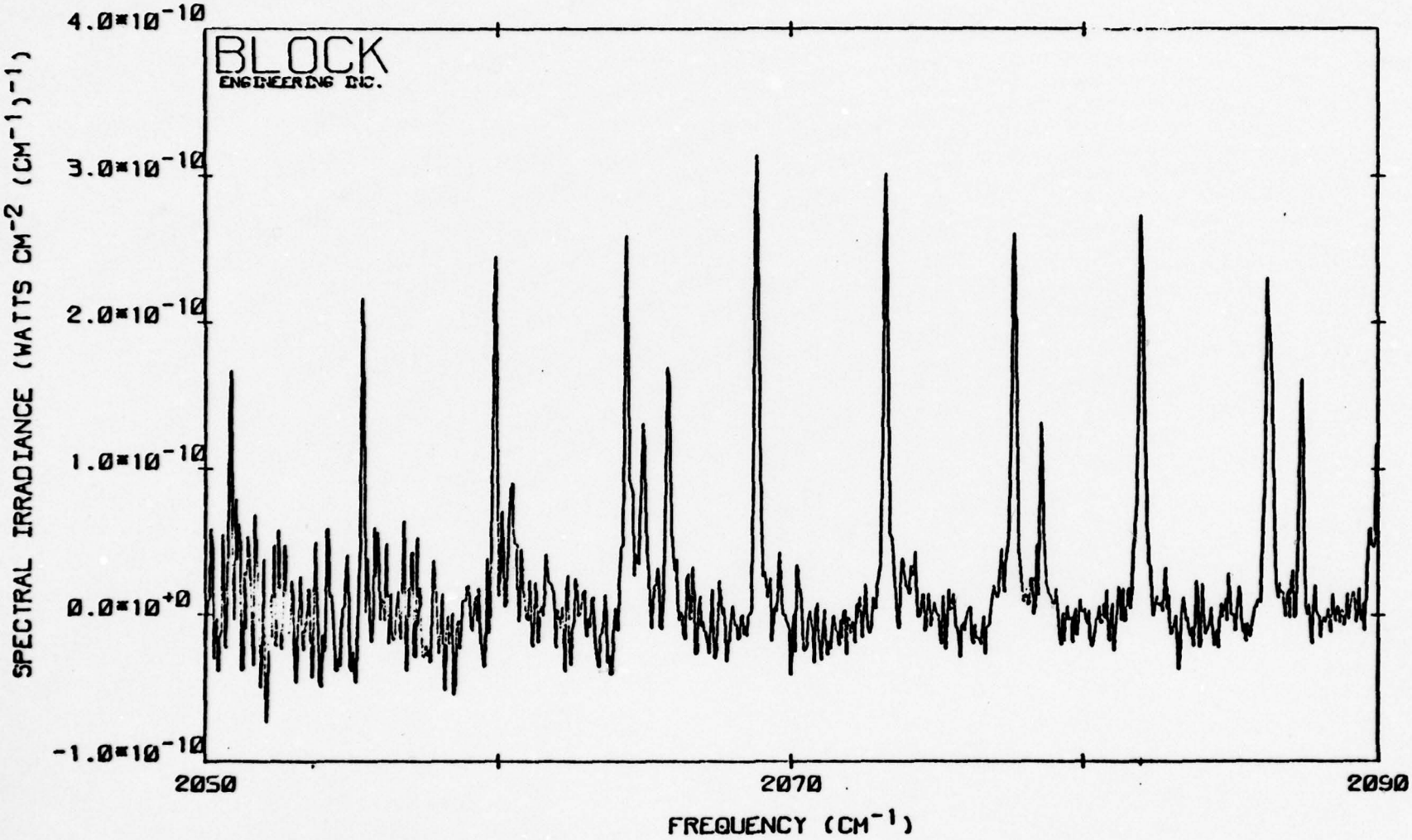

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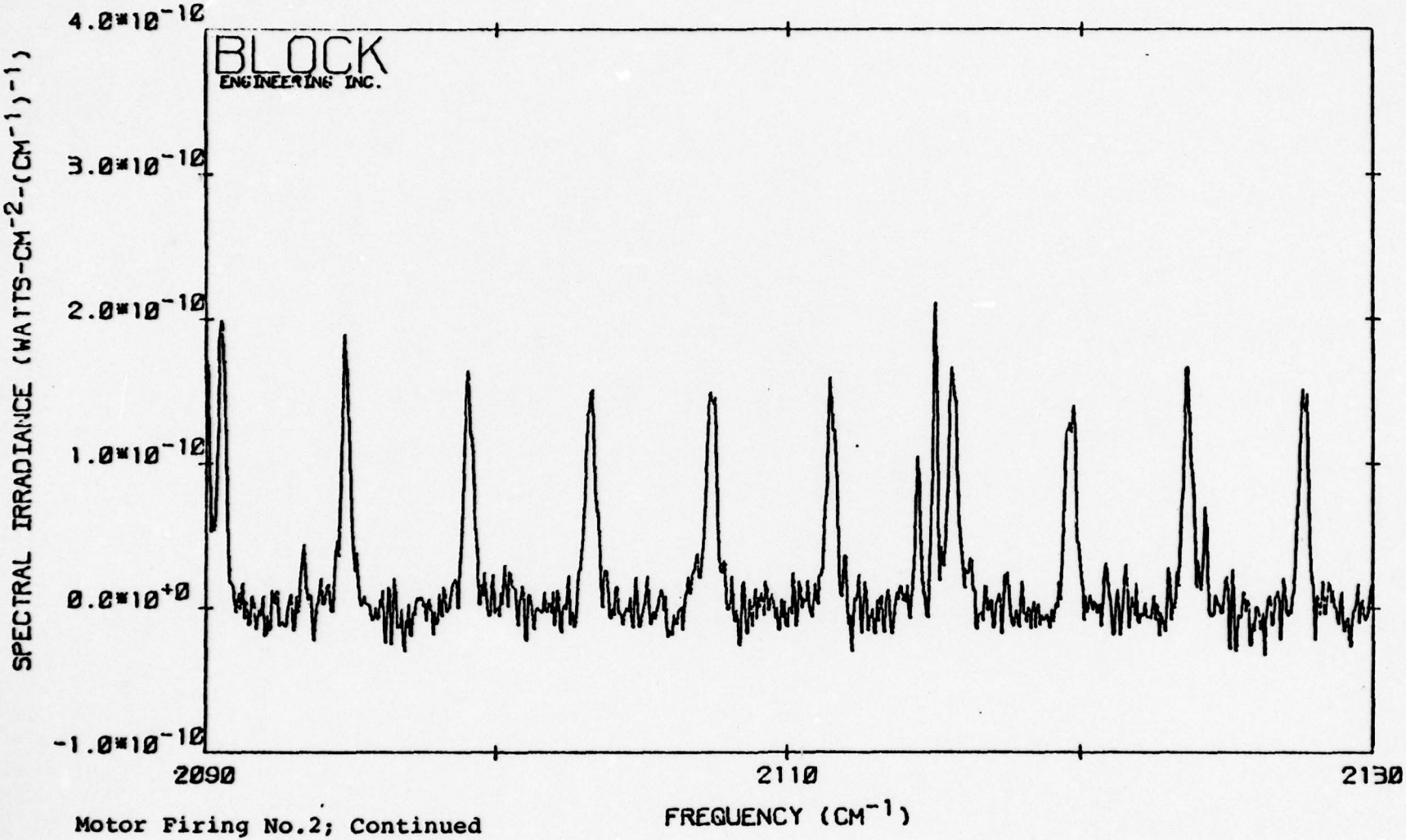

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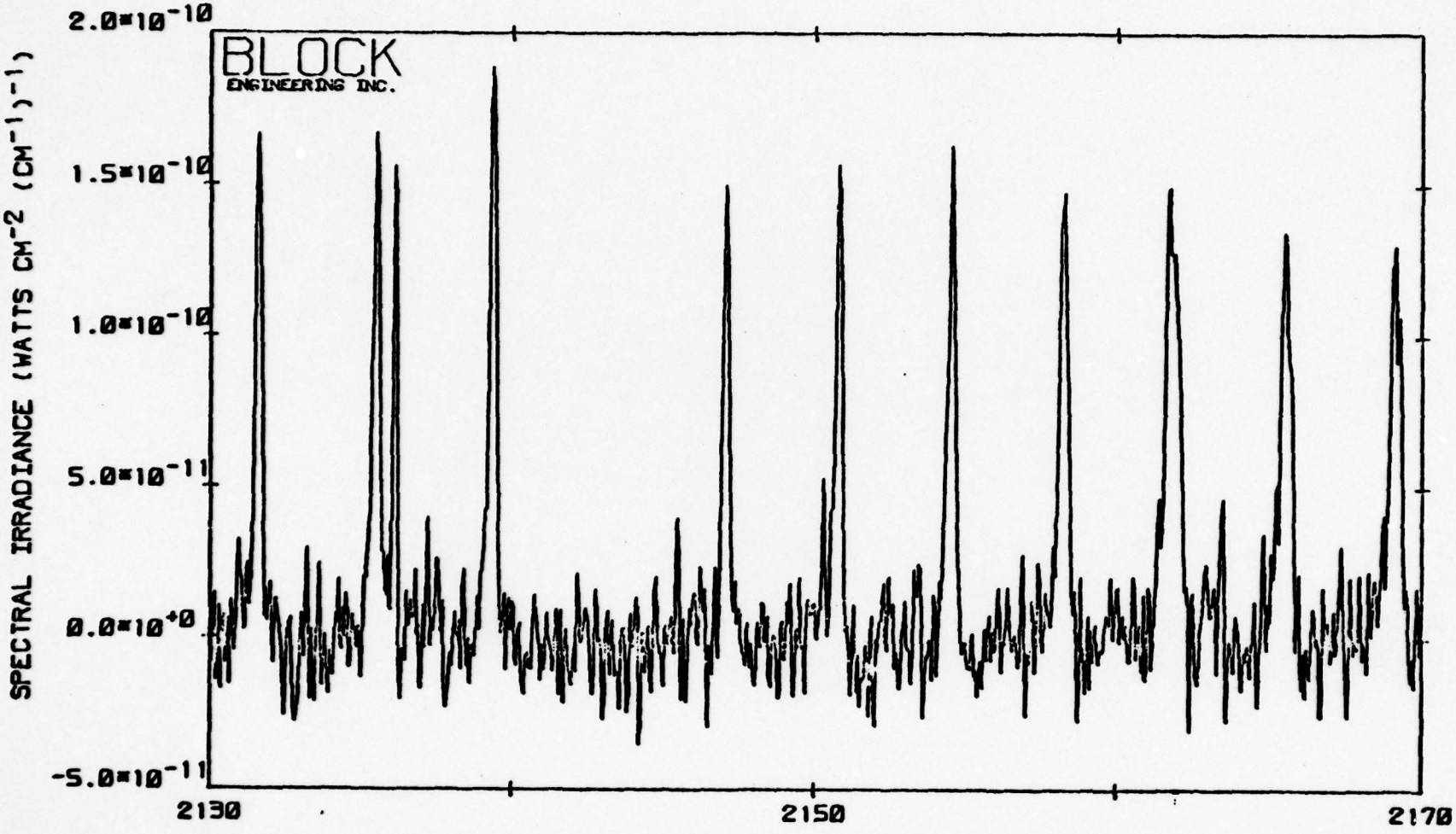

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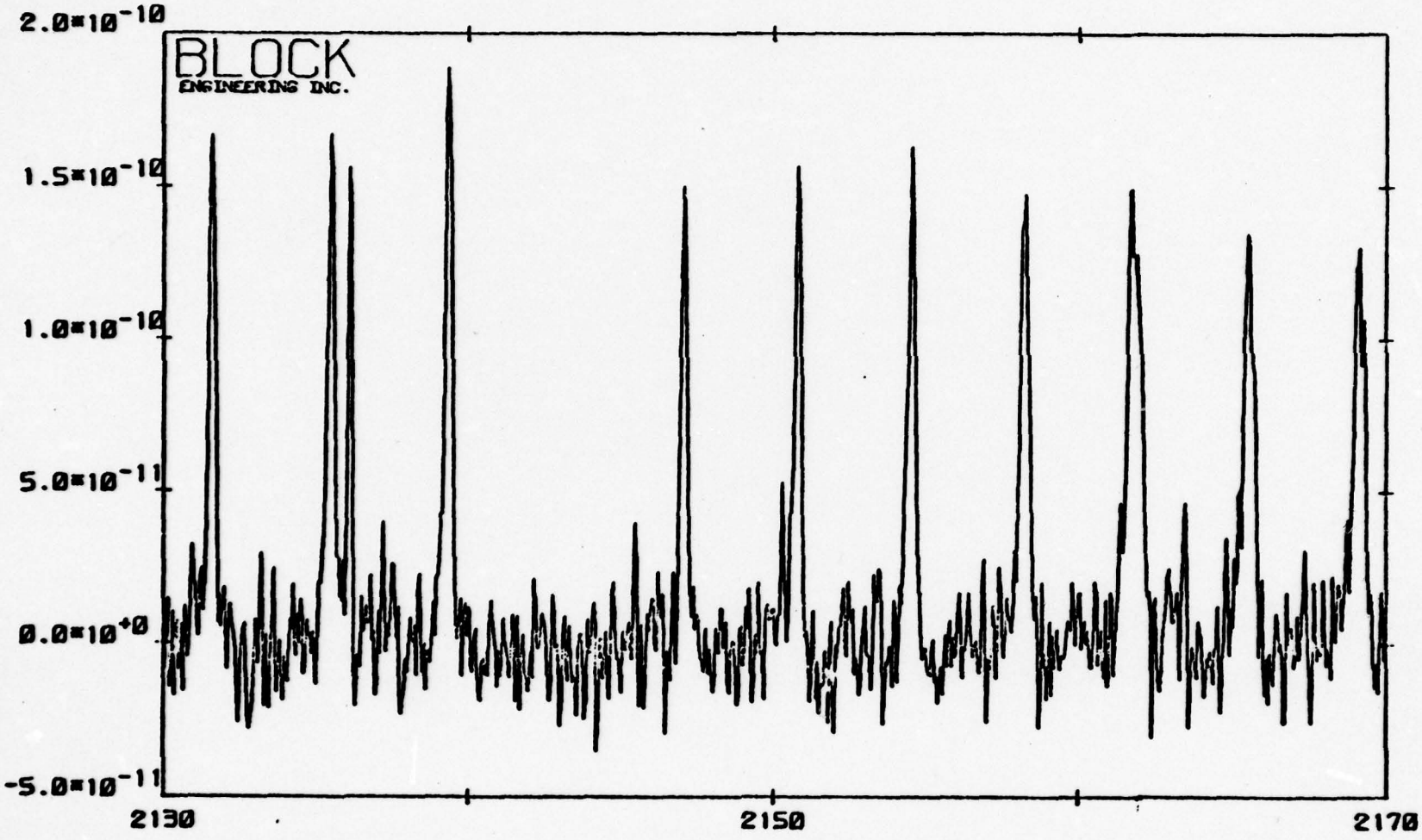

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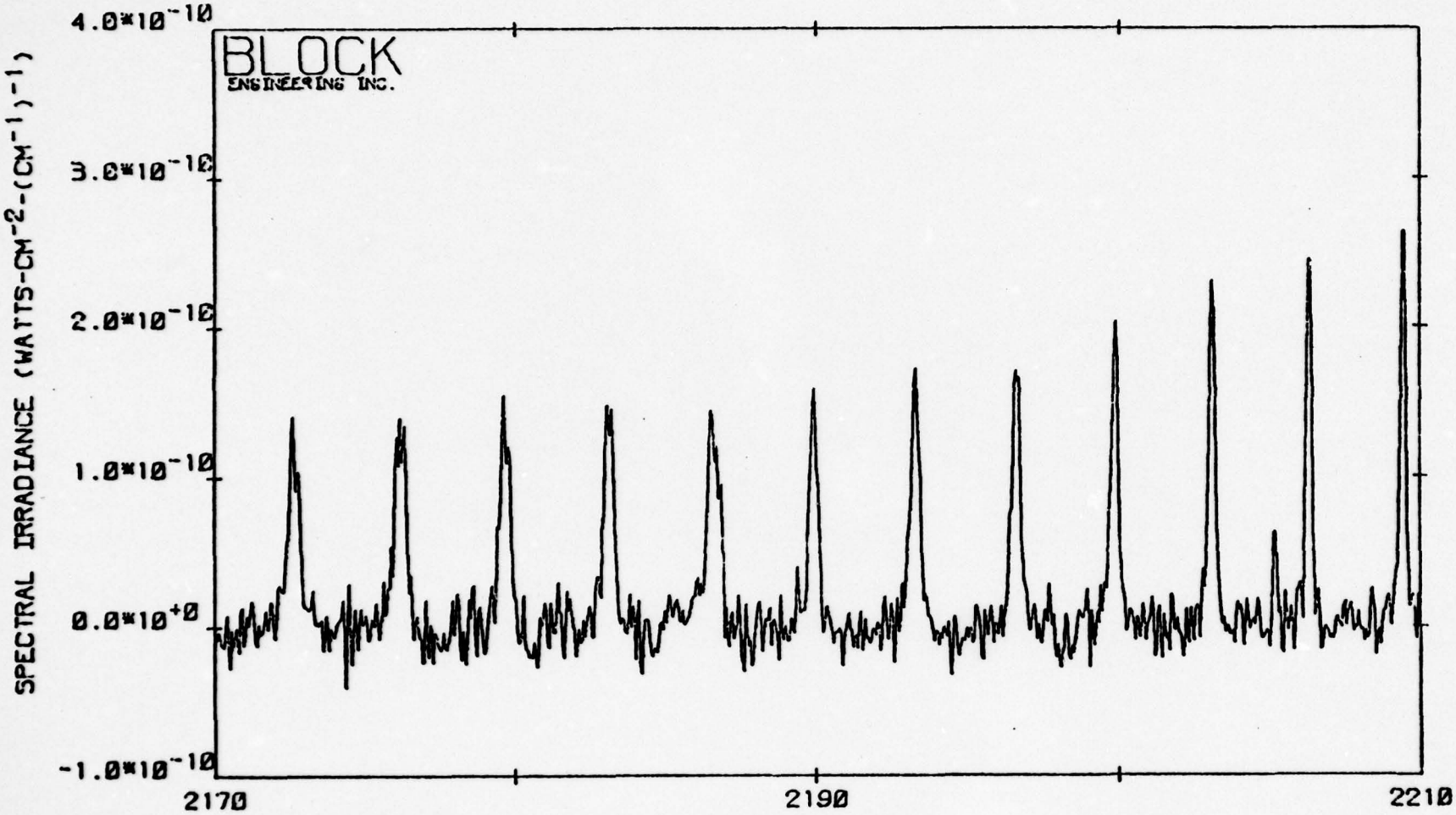

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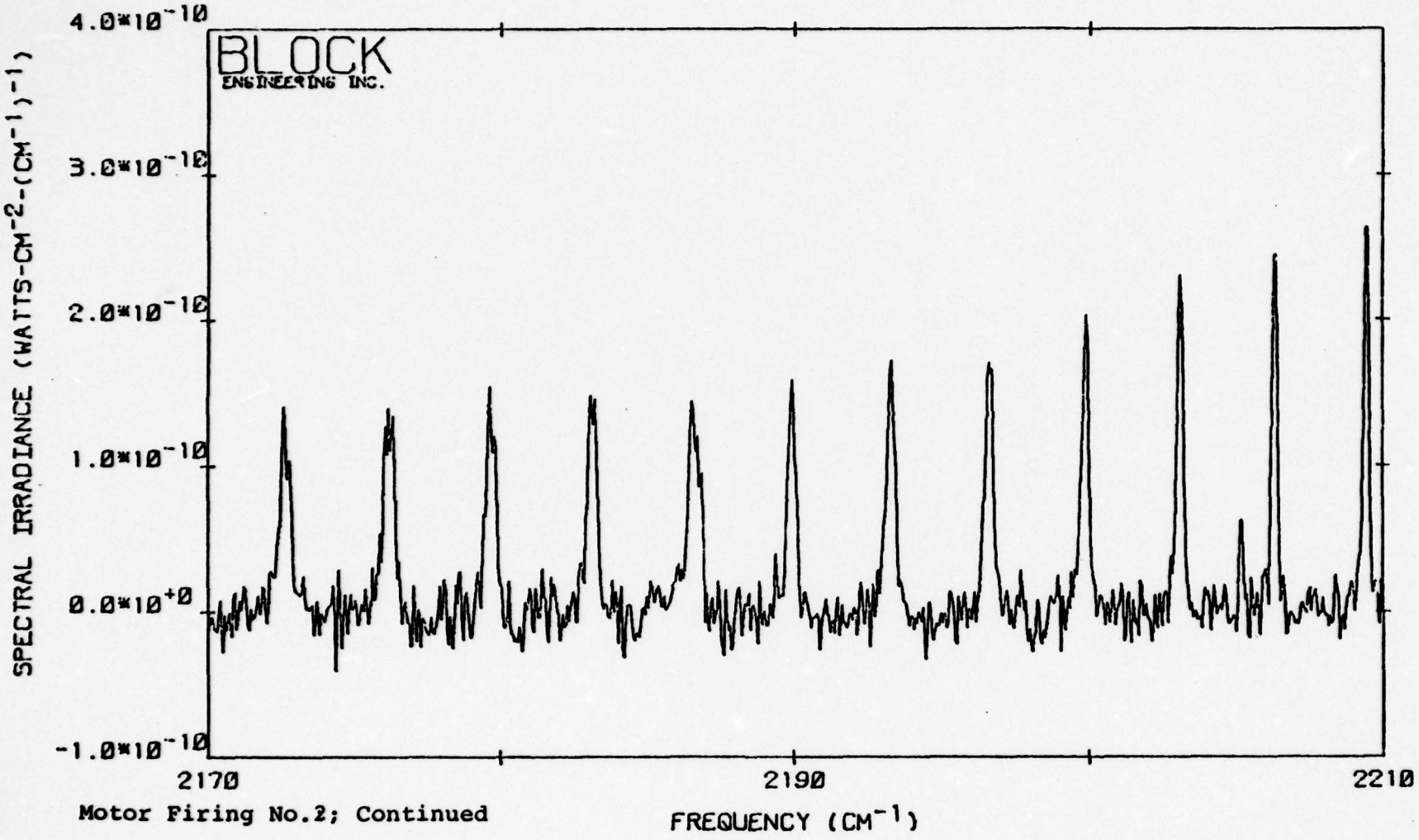

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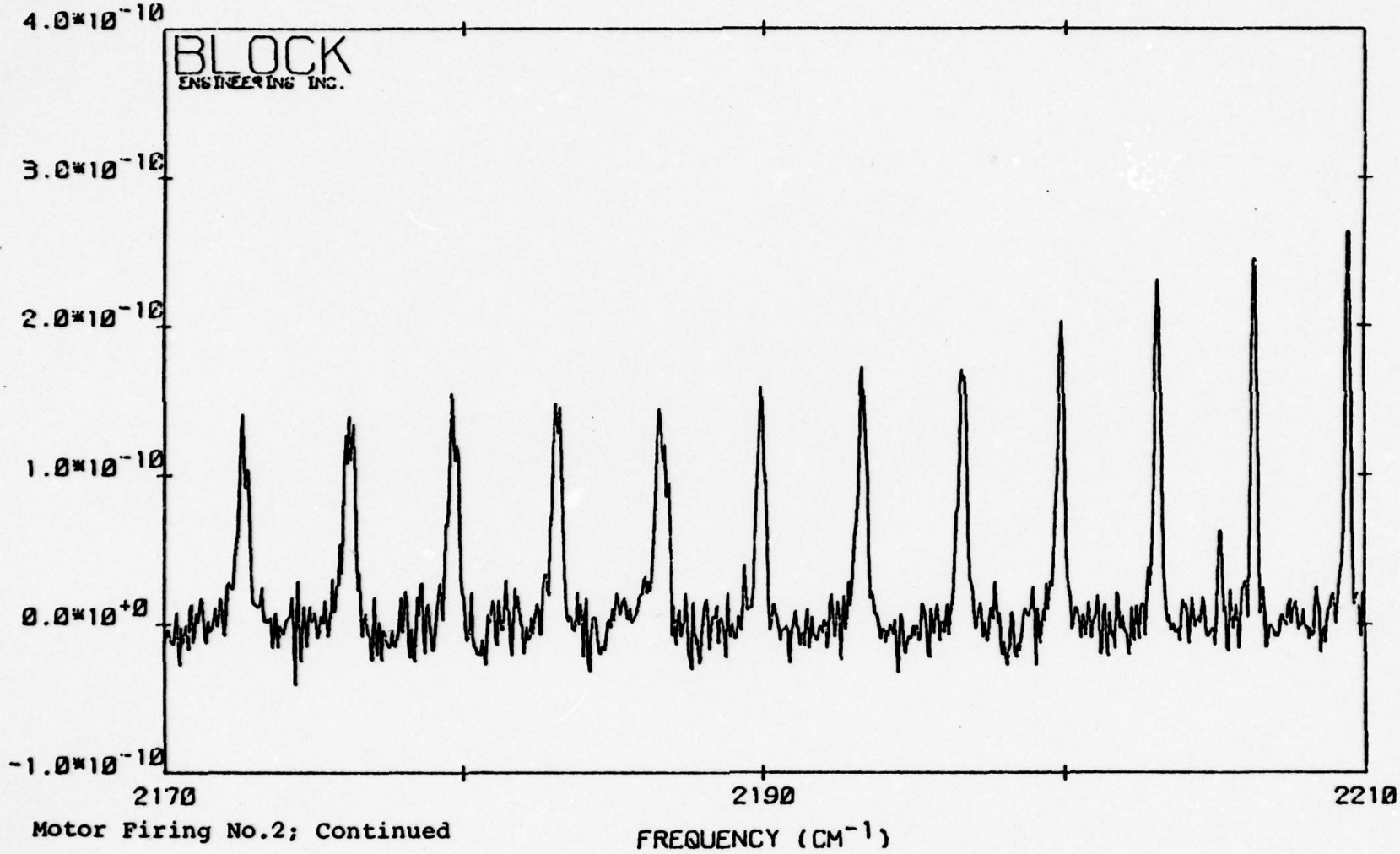

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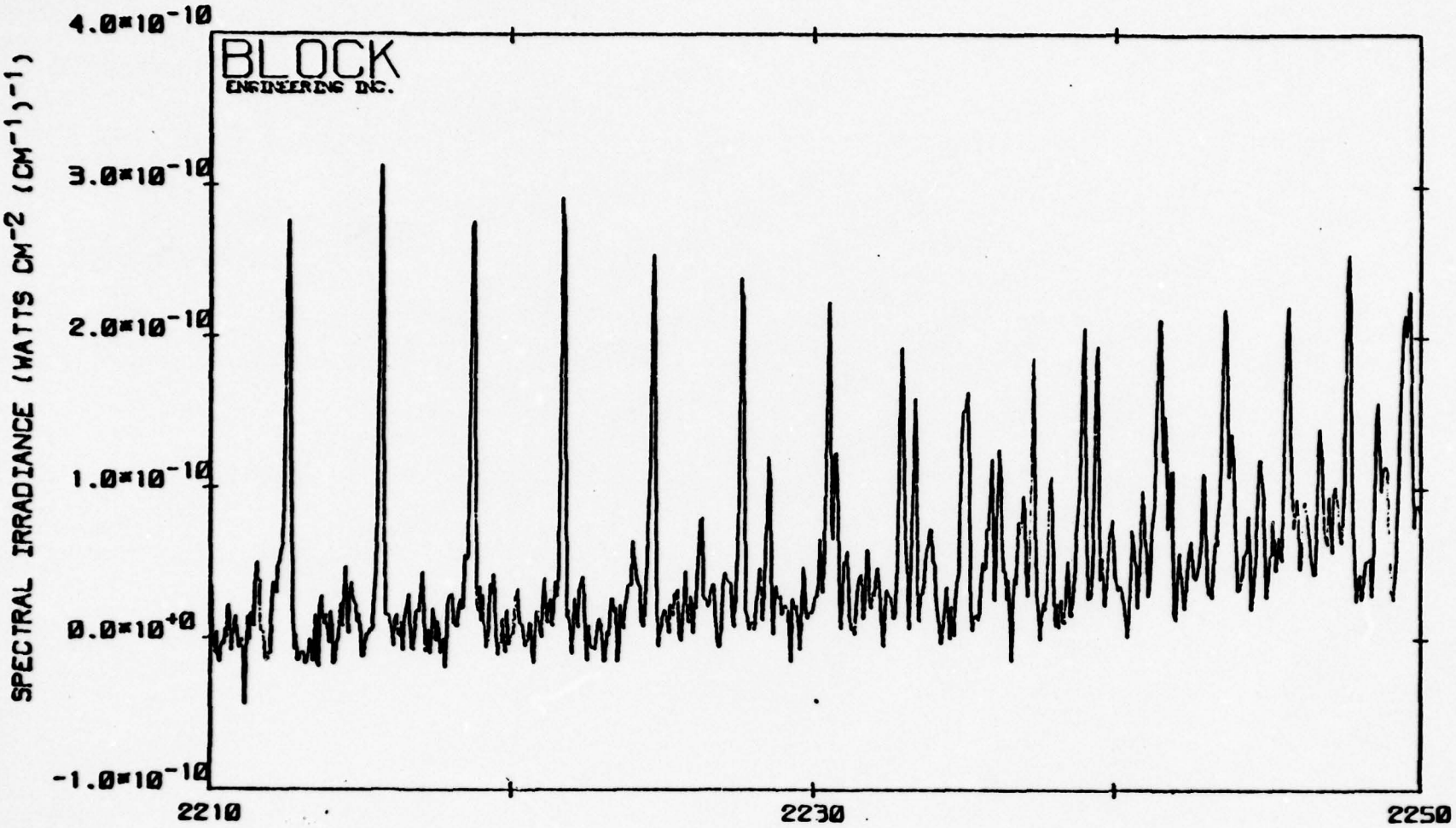

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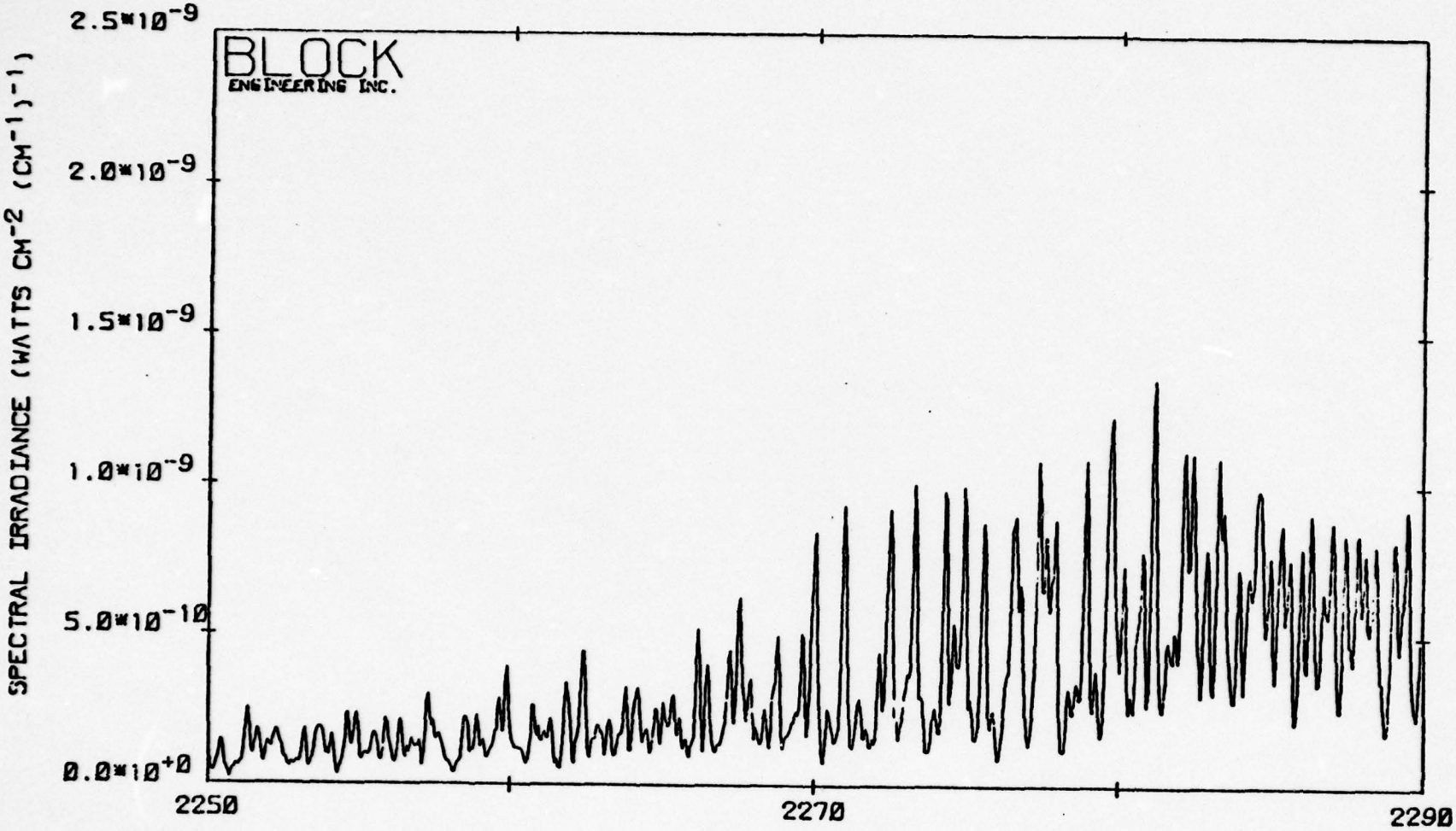

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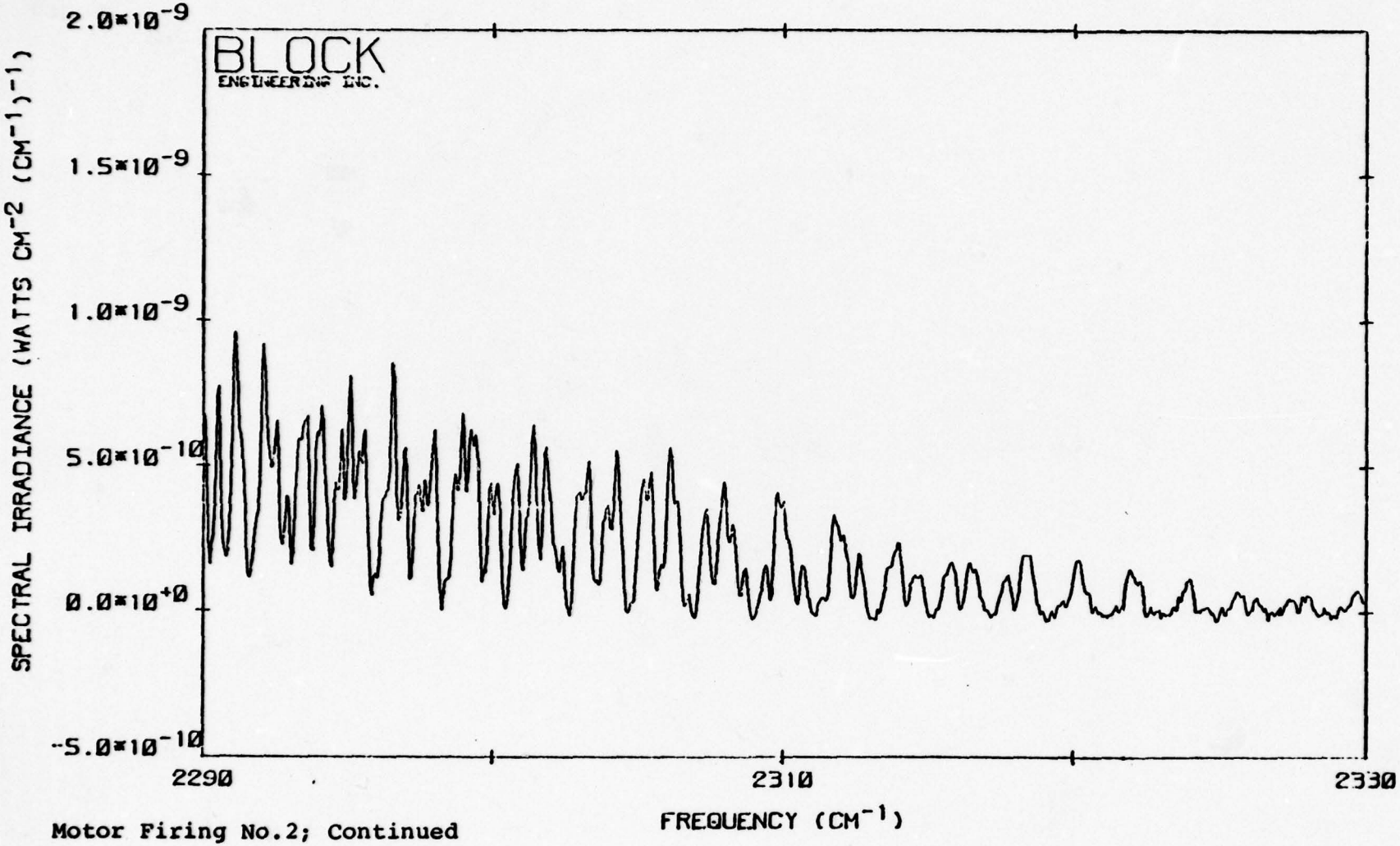

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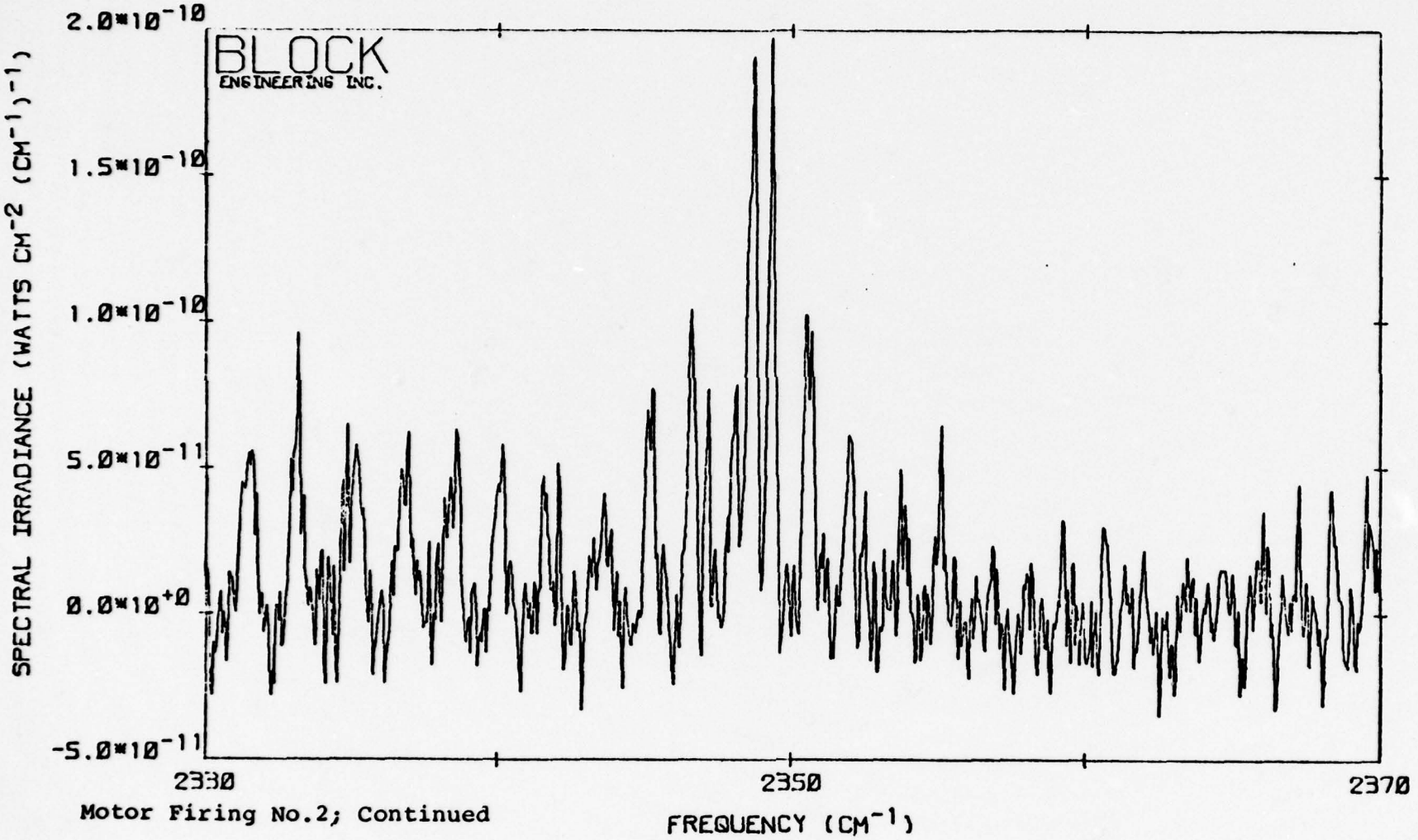

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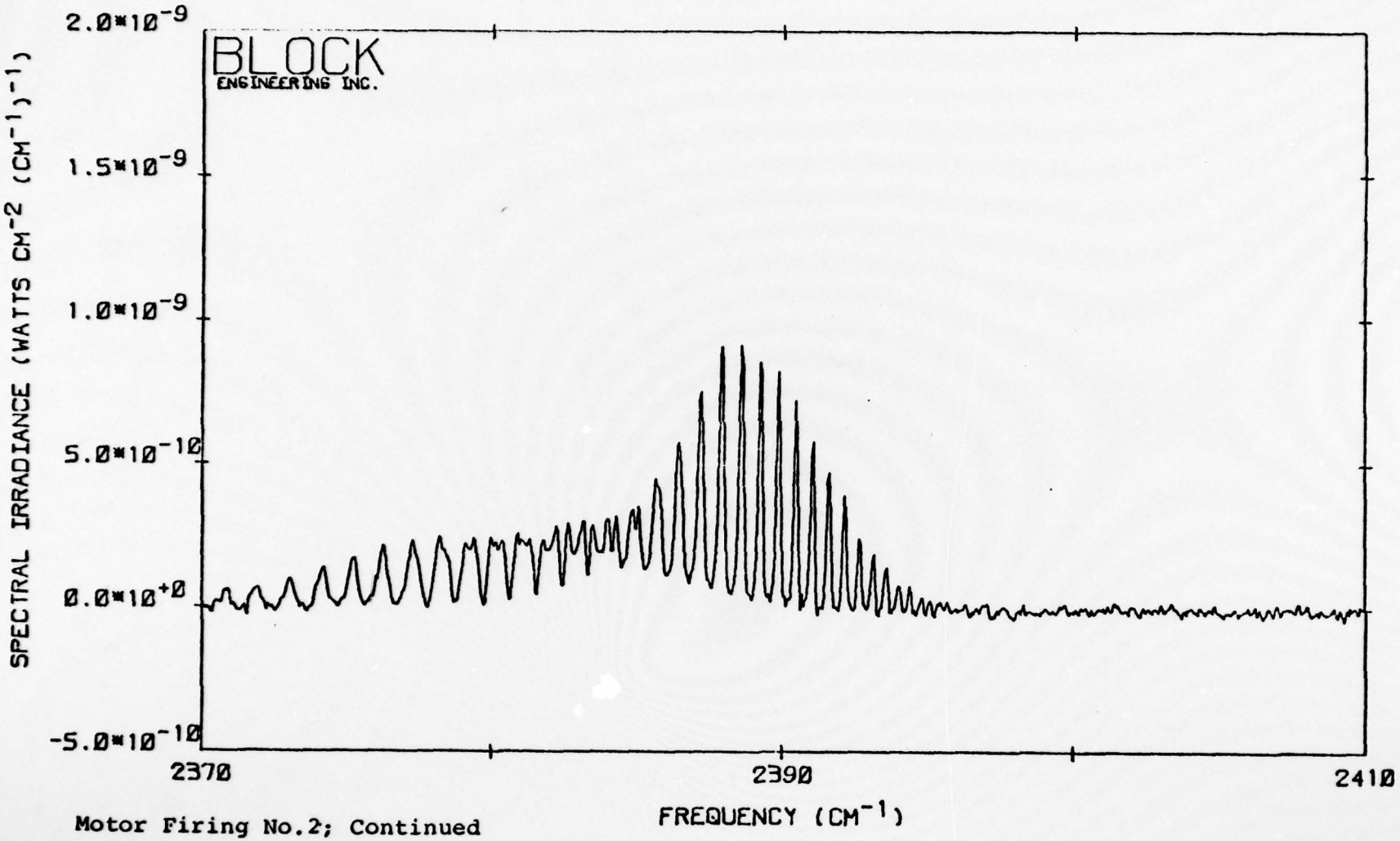

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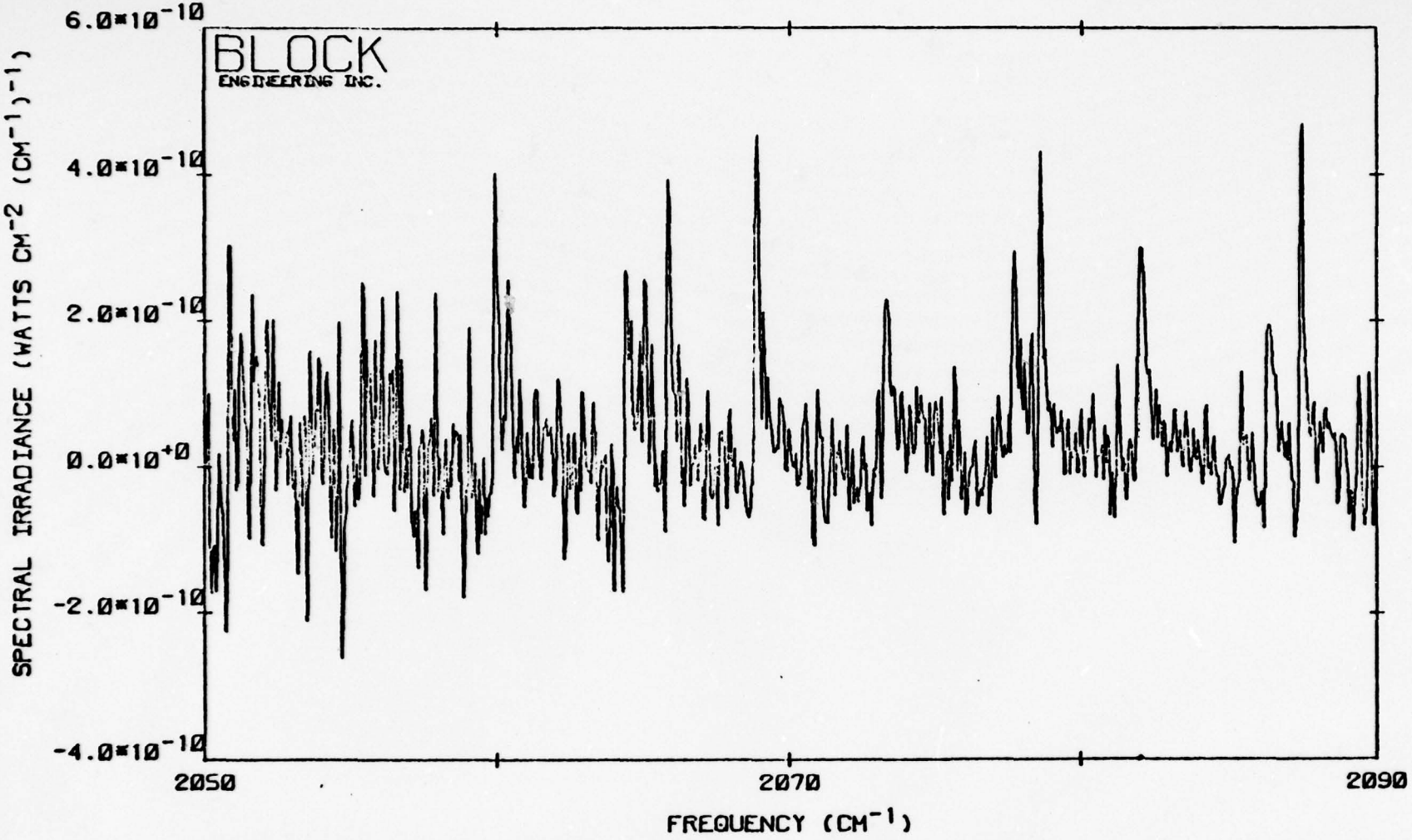

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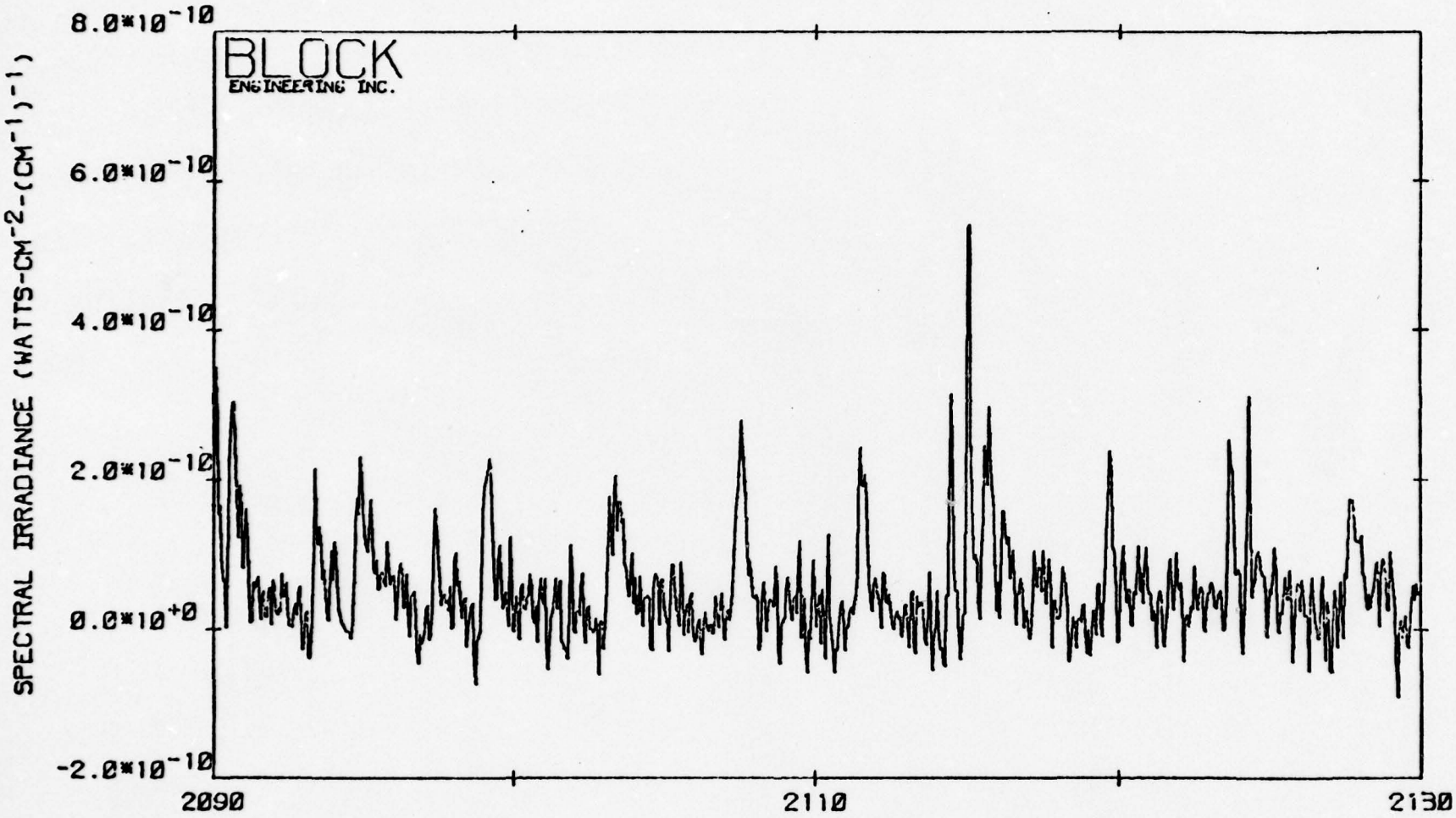

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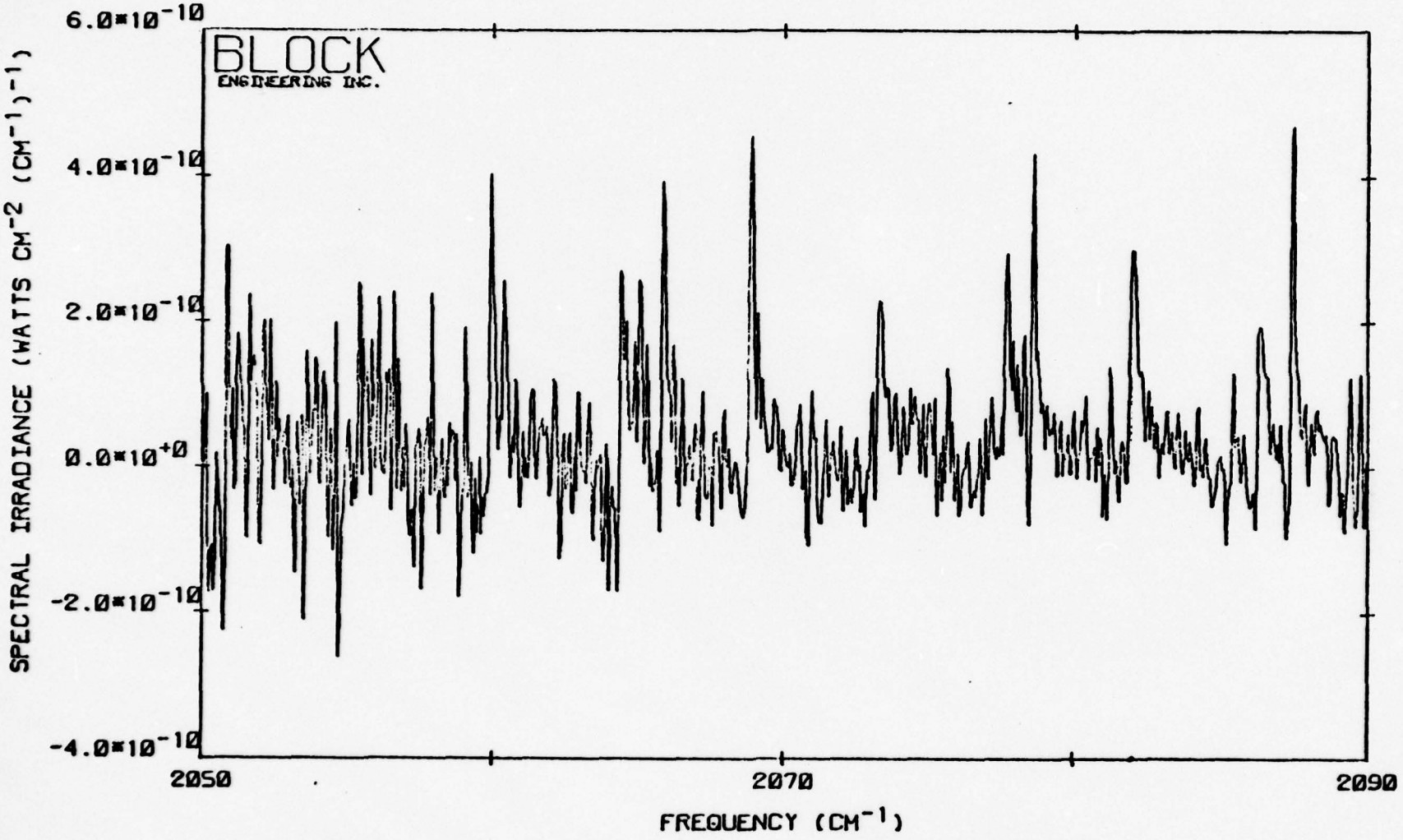

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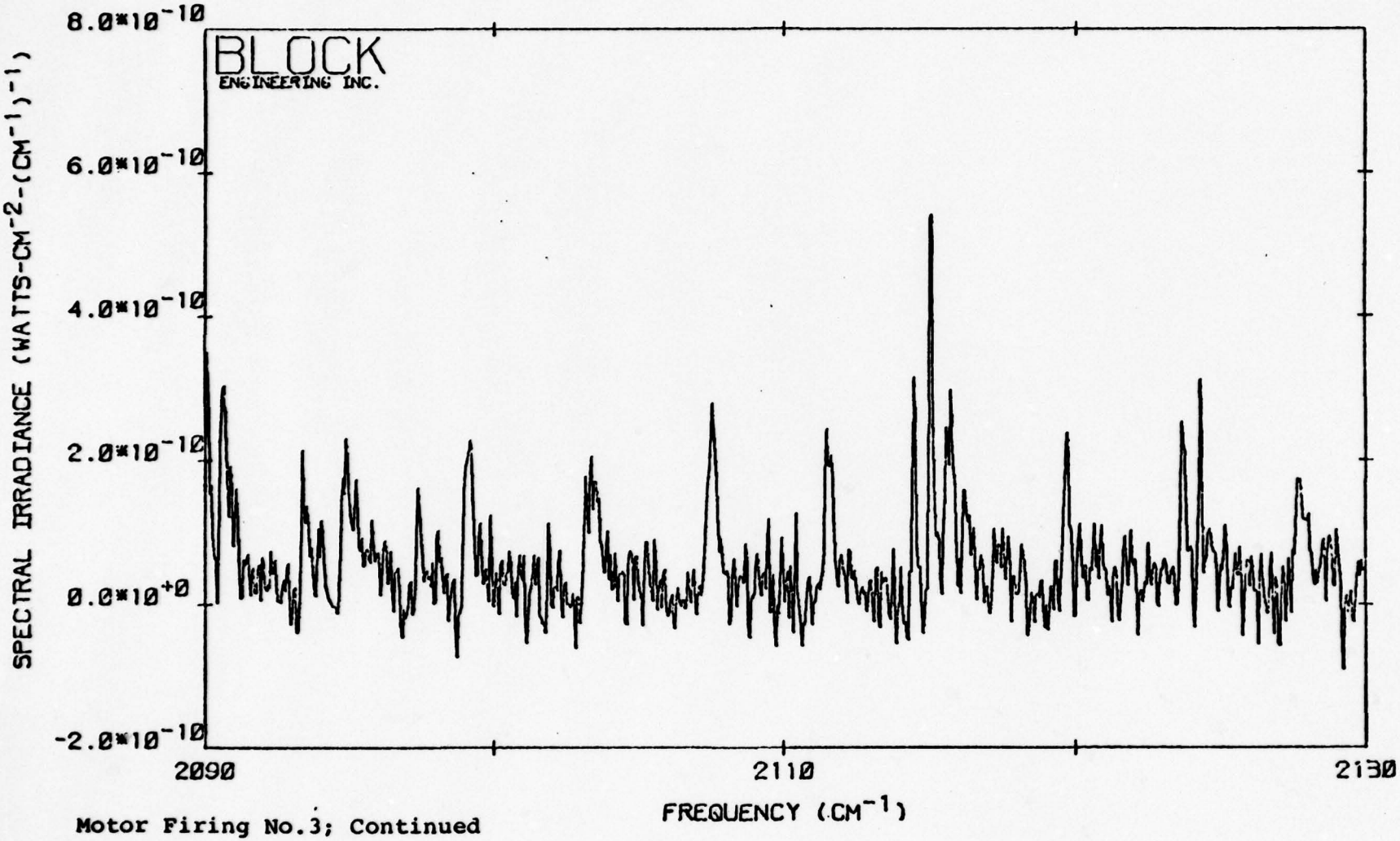
HF 3



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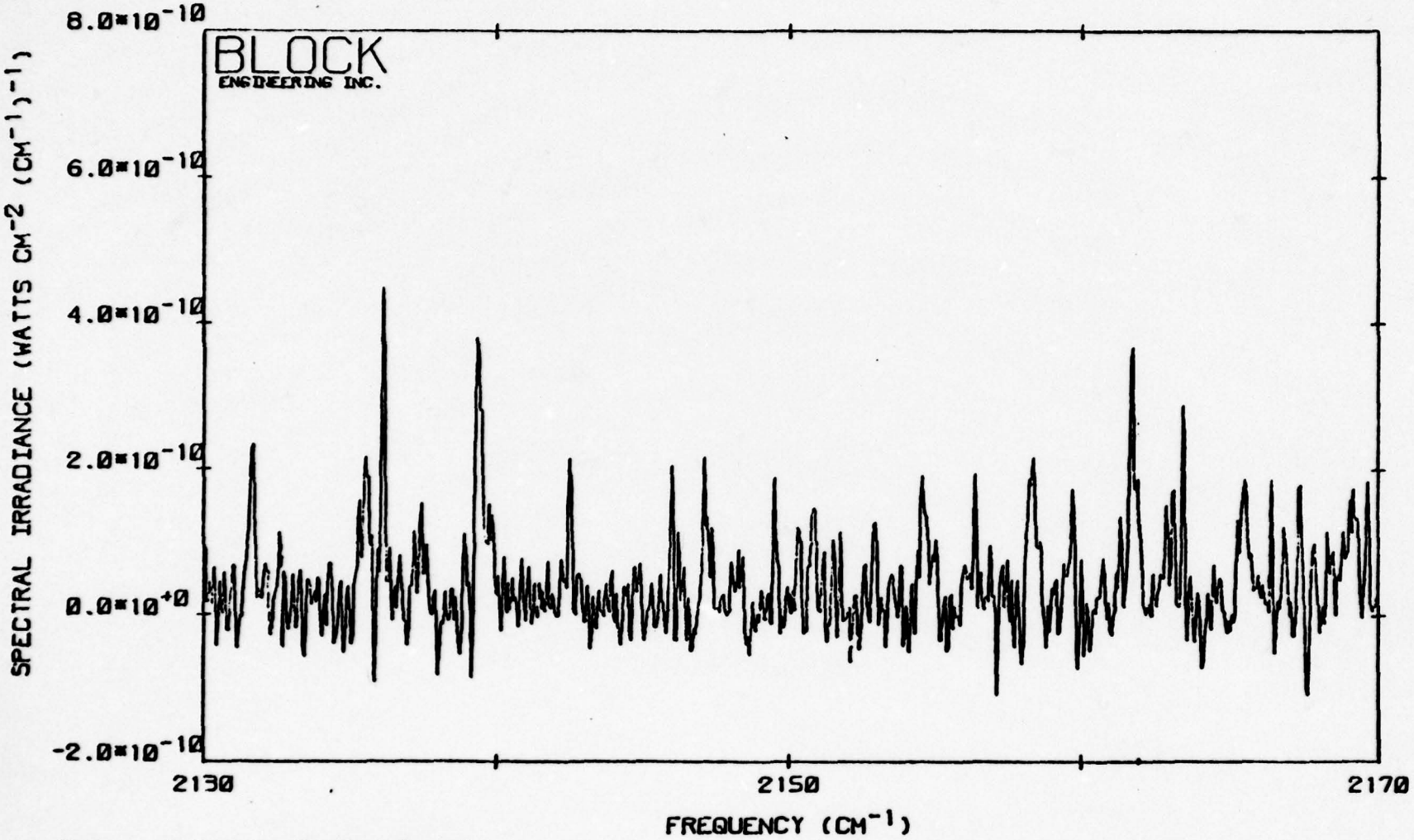

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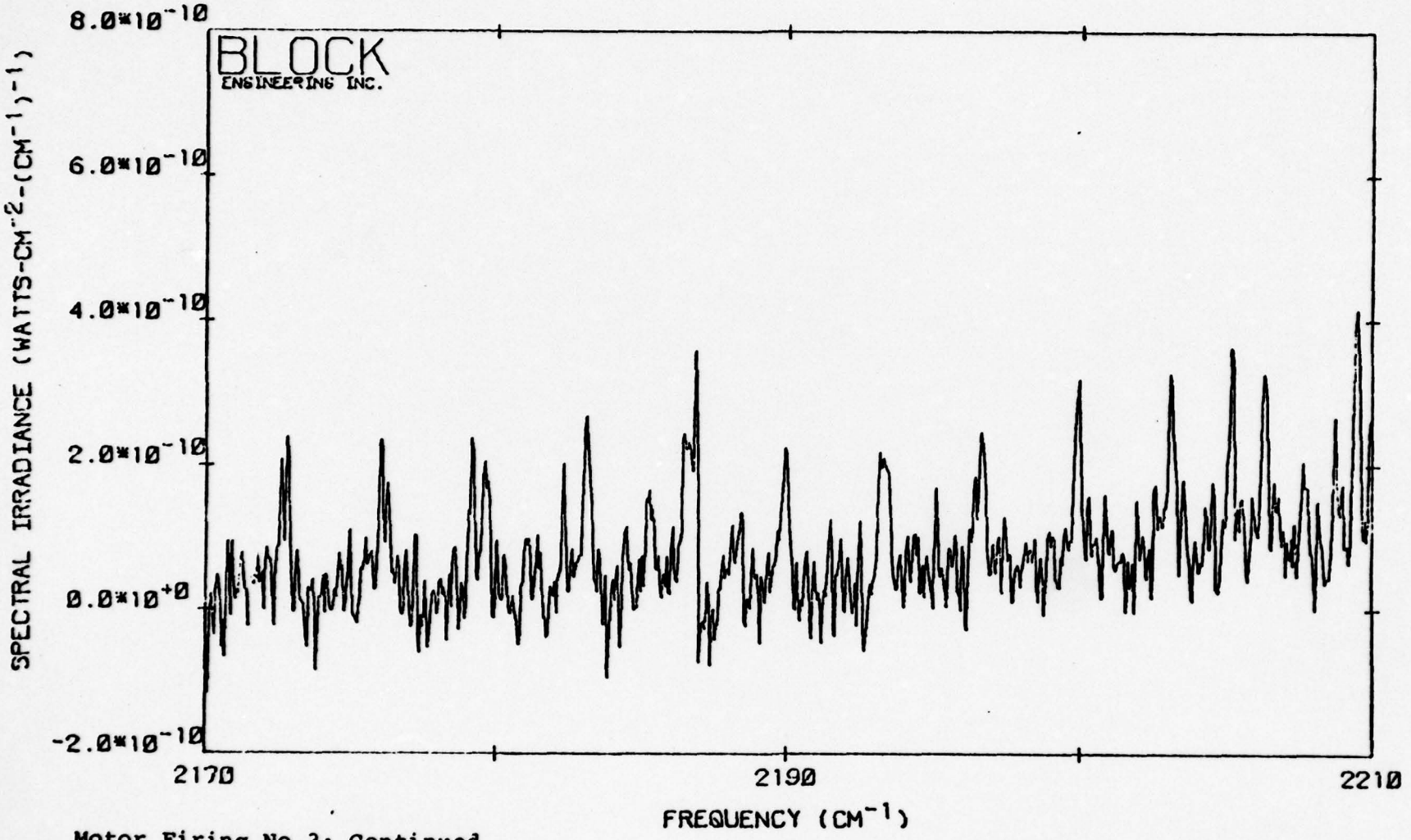

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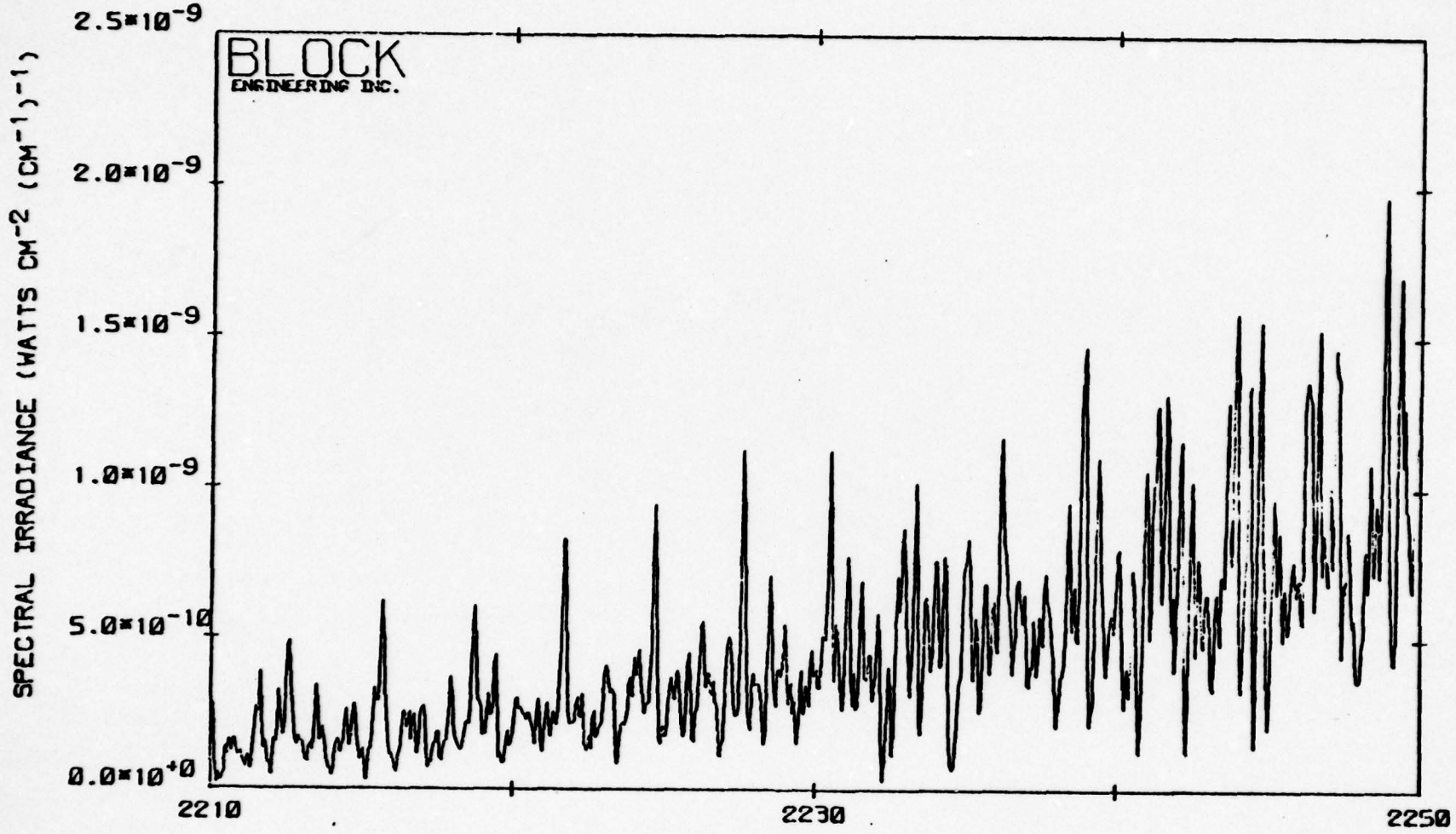

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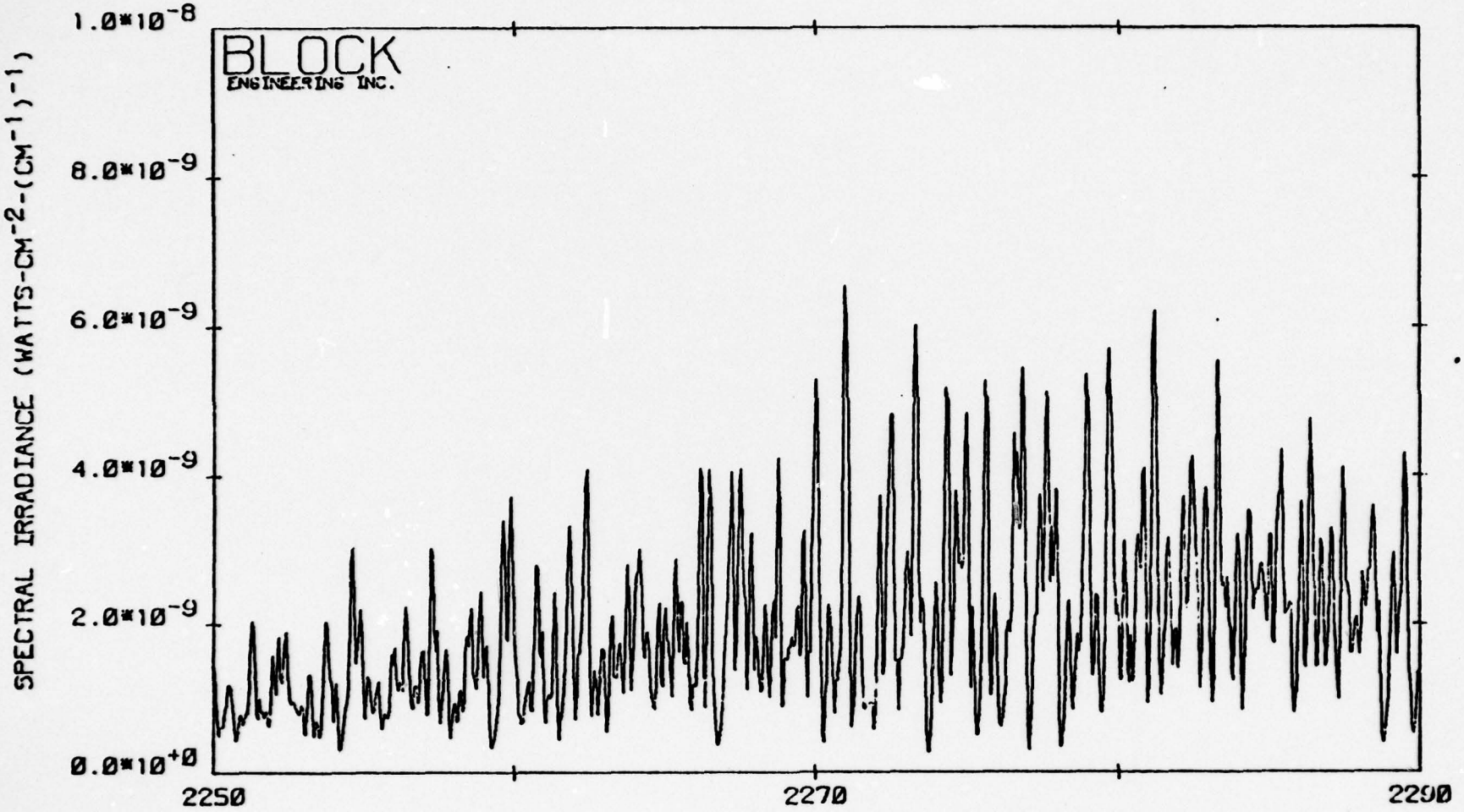

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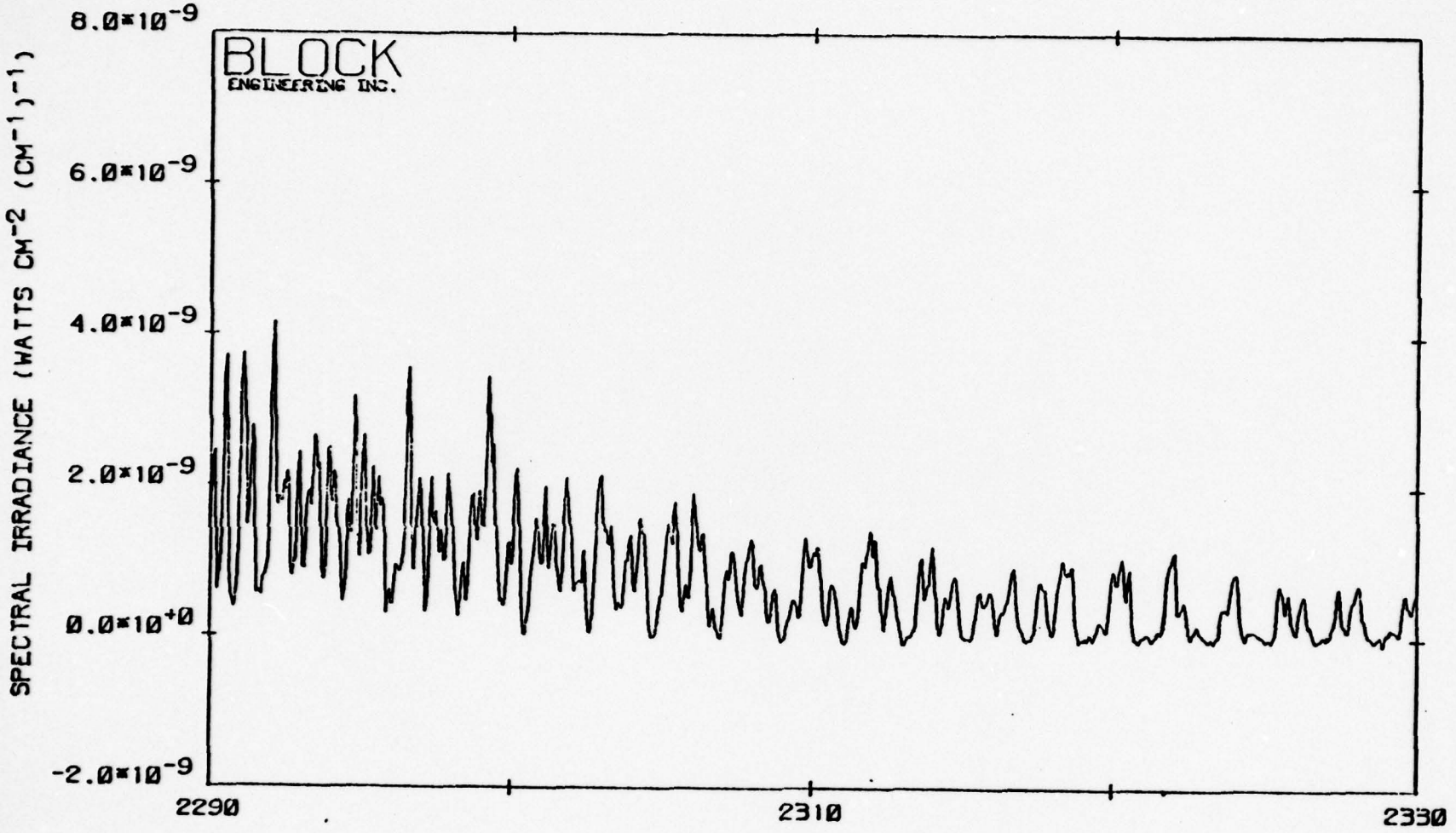

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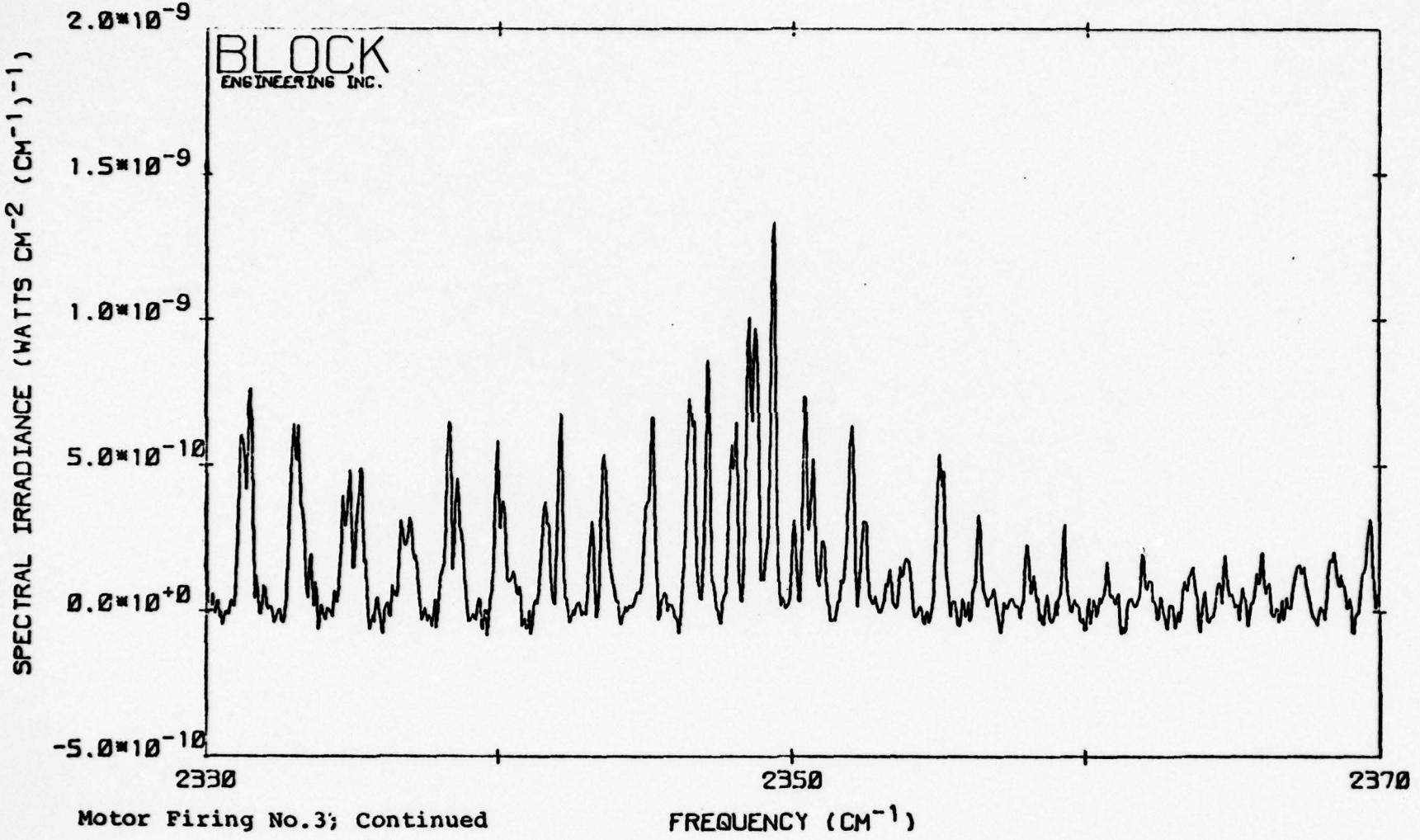

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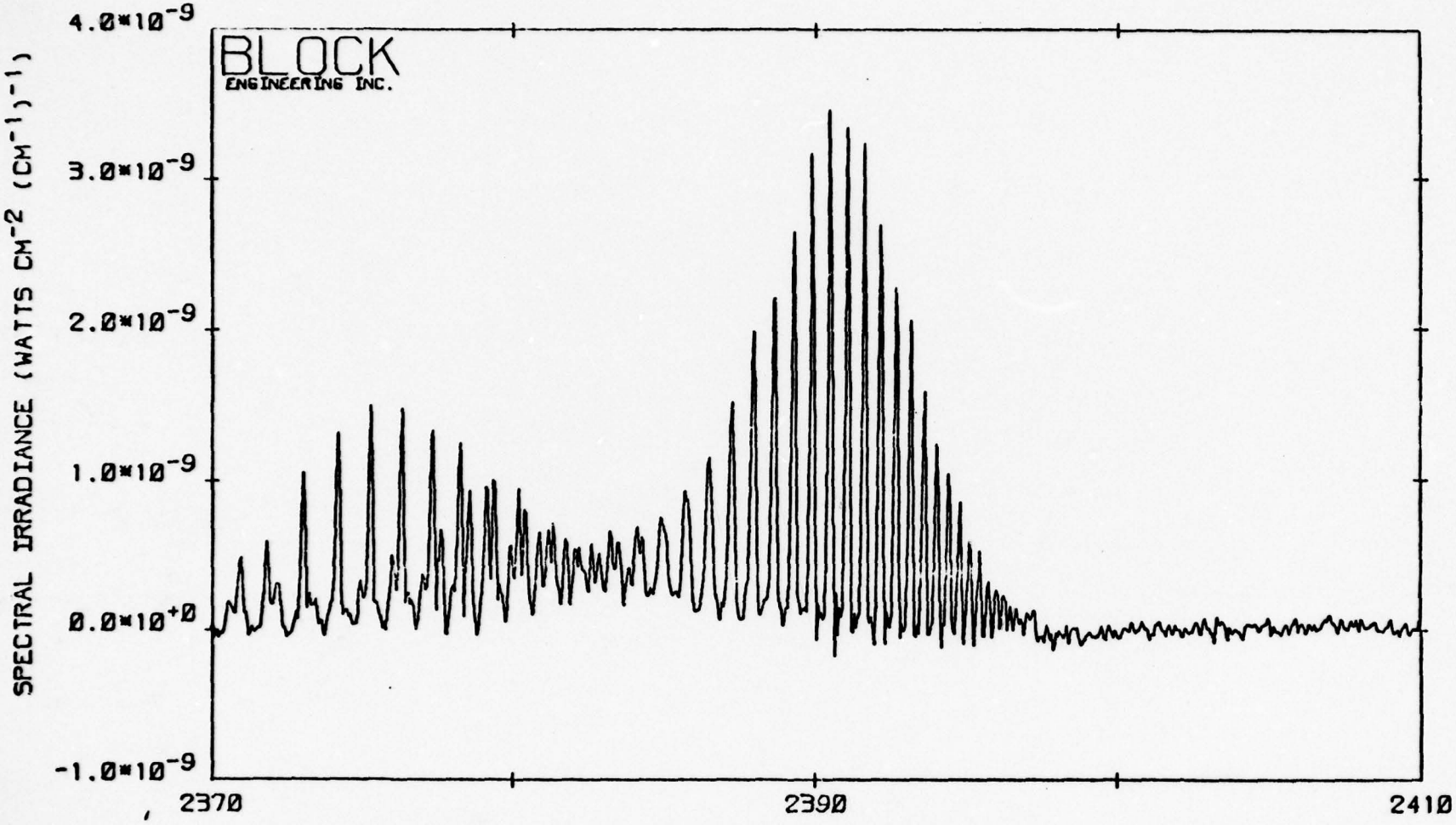

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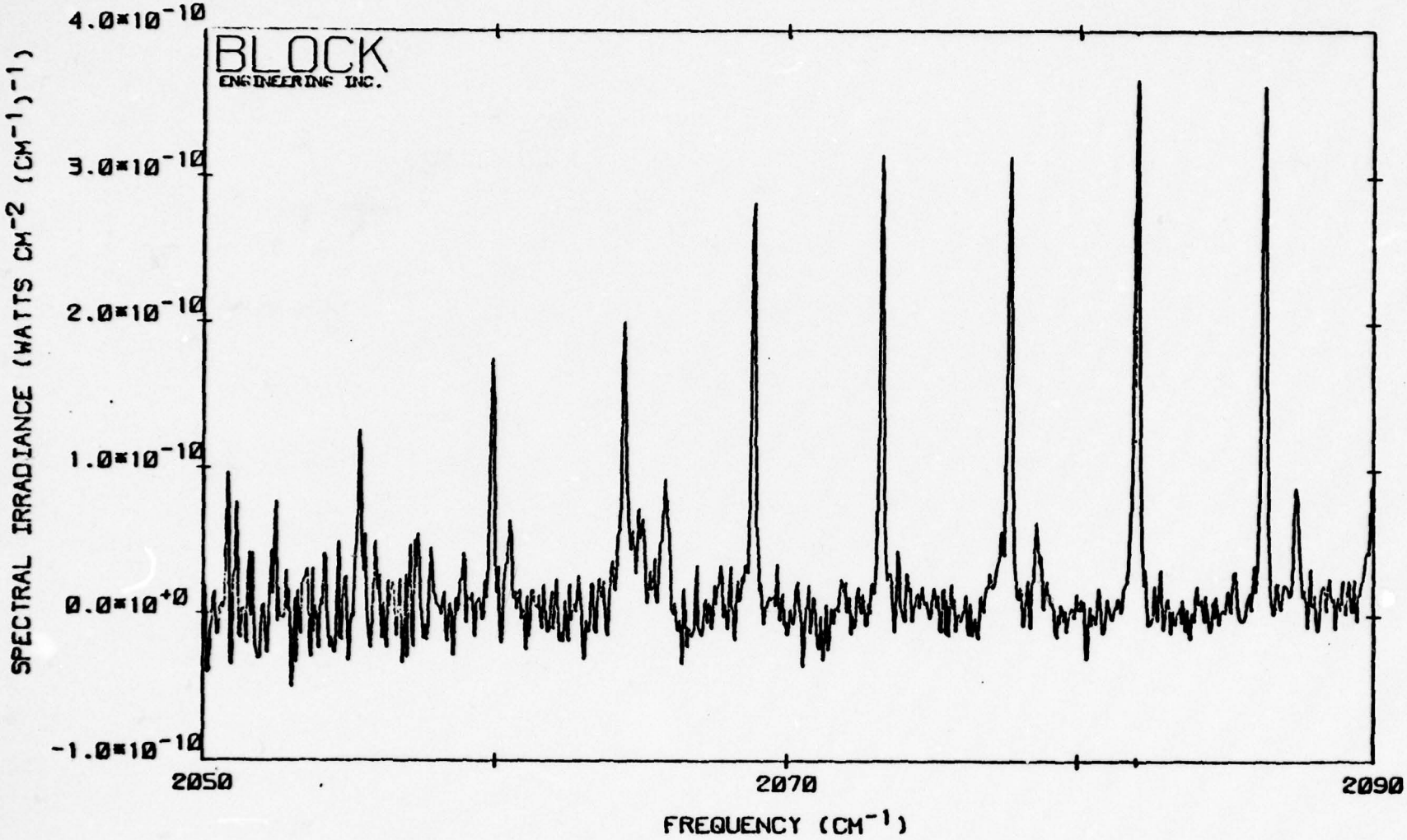
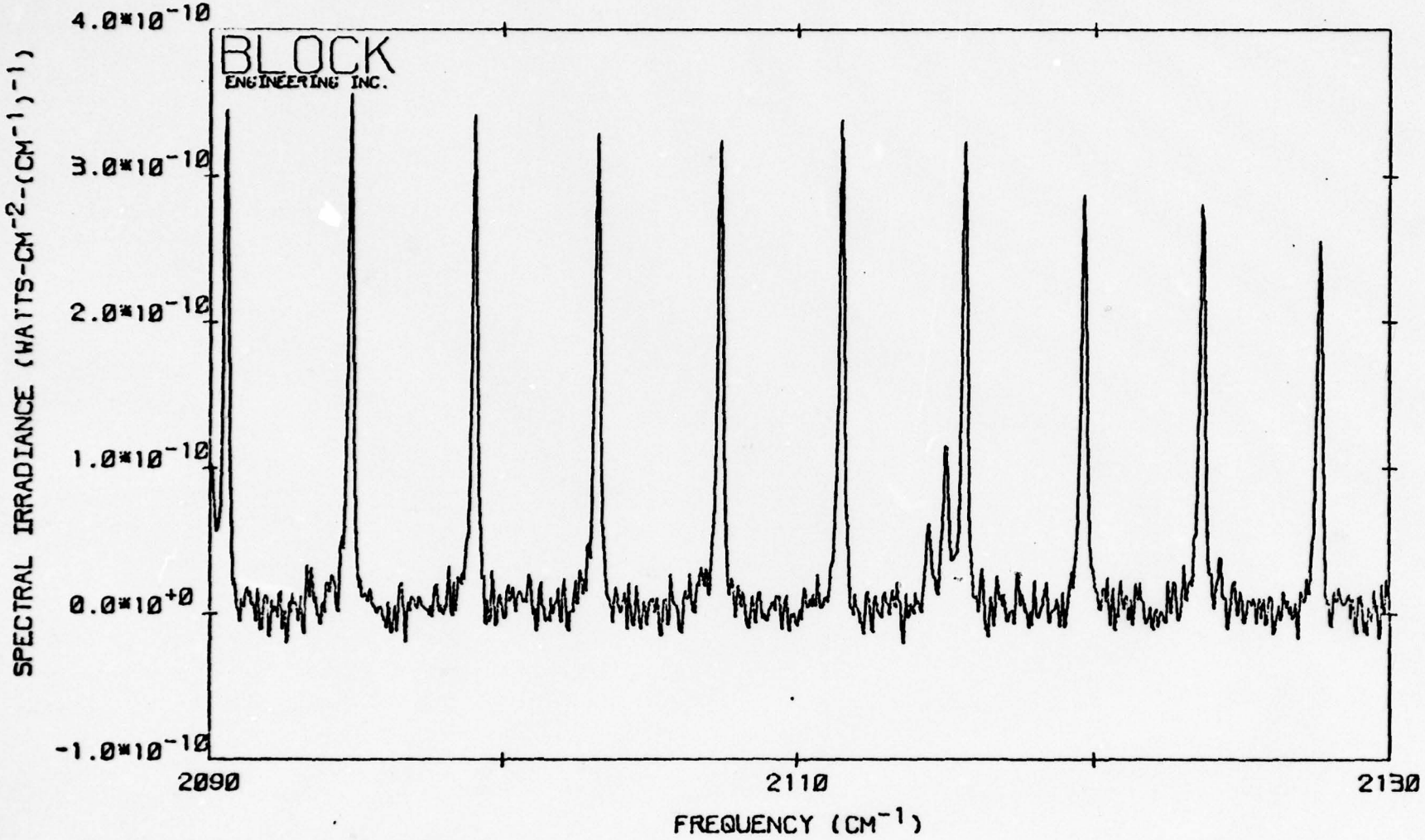
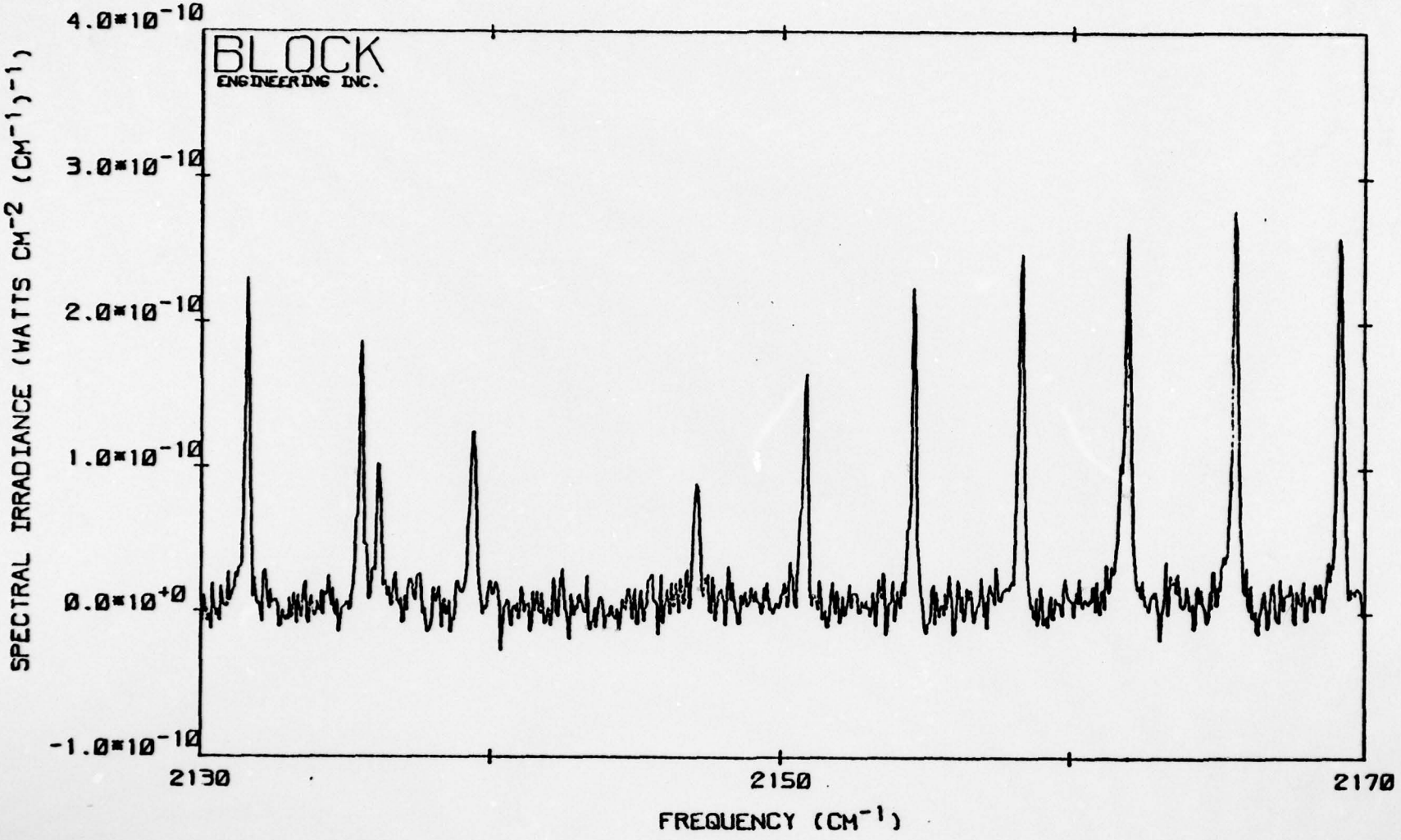


Motor Firing No.4; 0 km Altitude; 35 cm From Exit Plane



Motor Firing No.4; Continued



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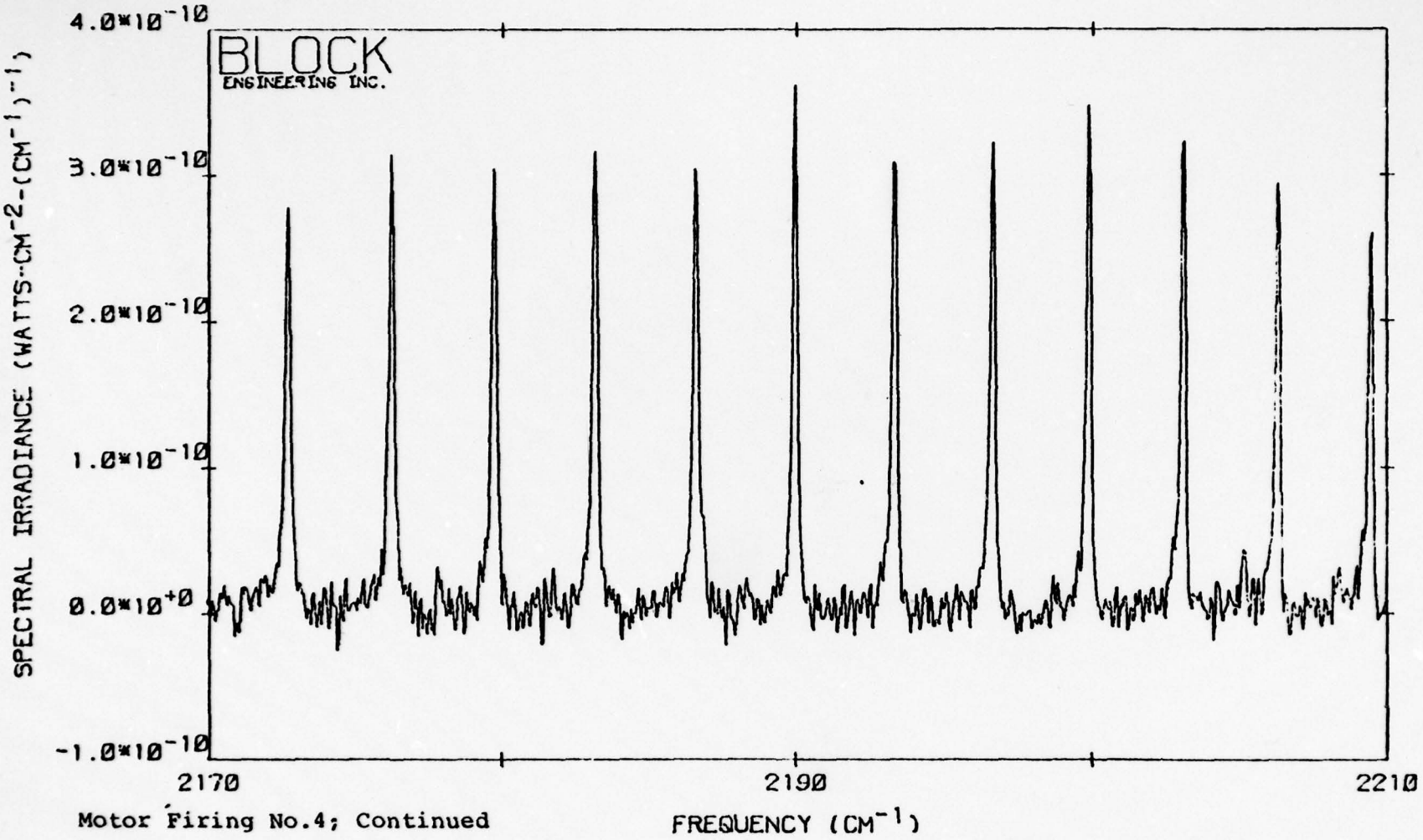

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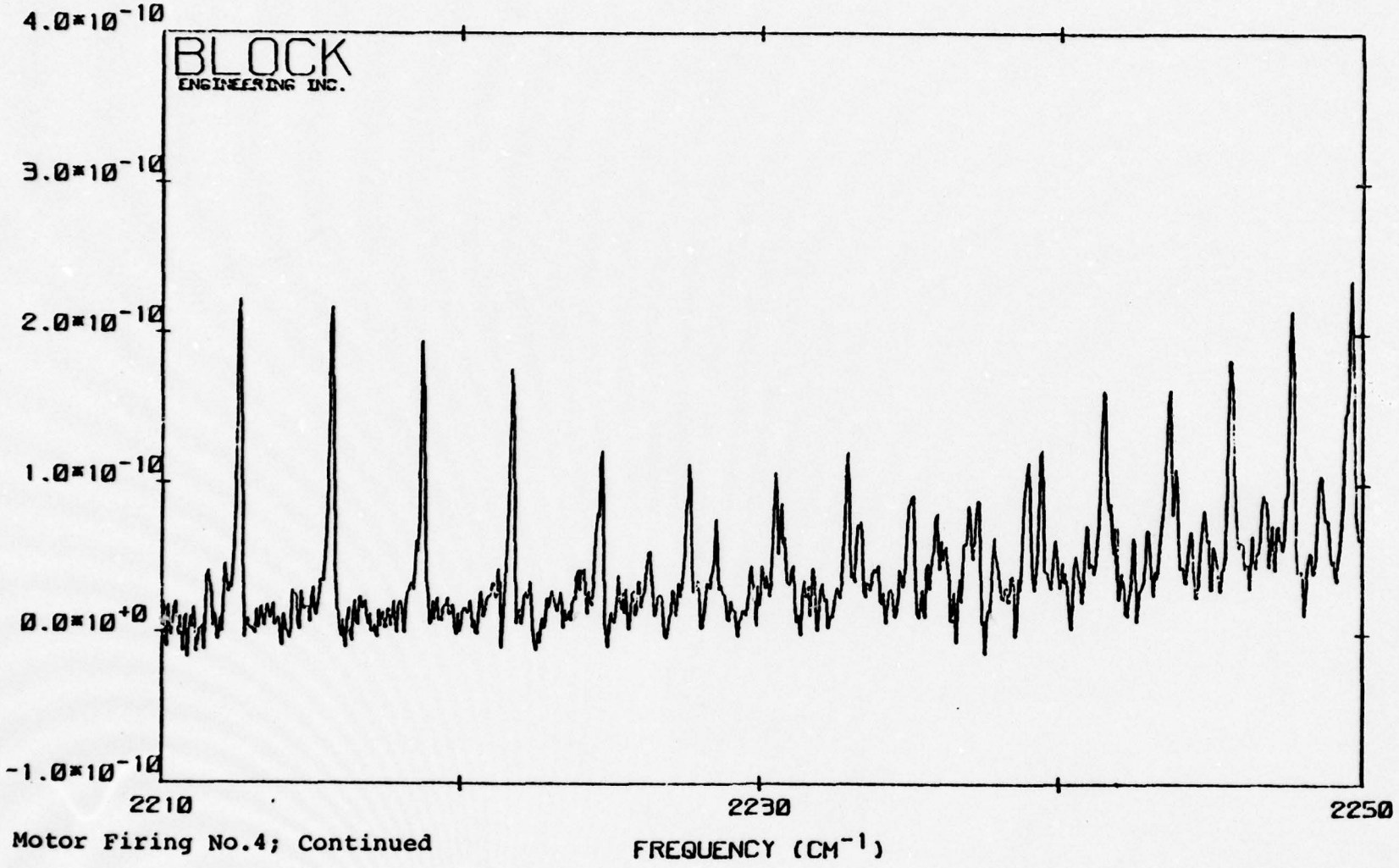

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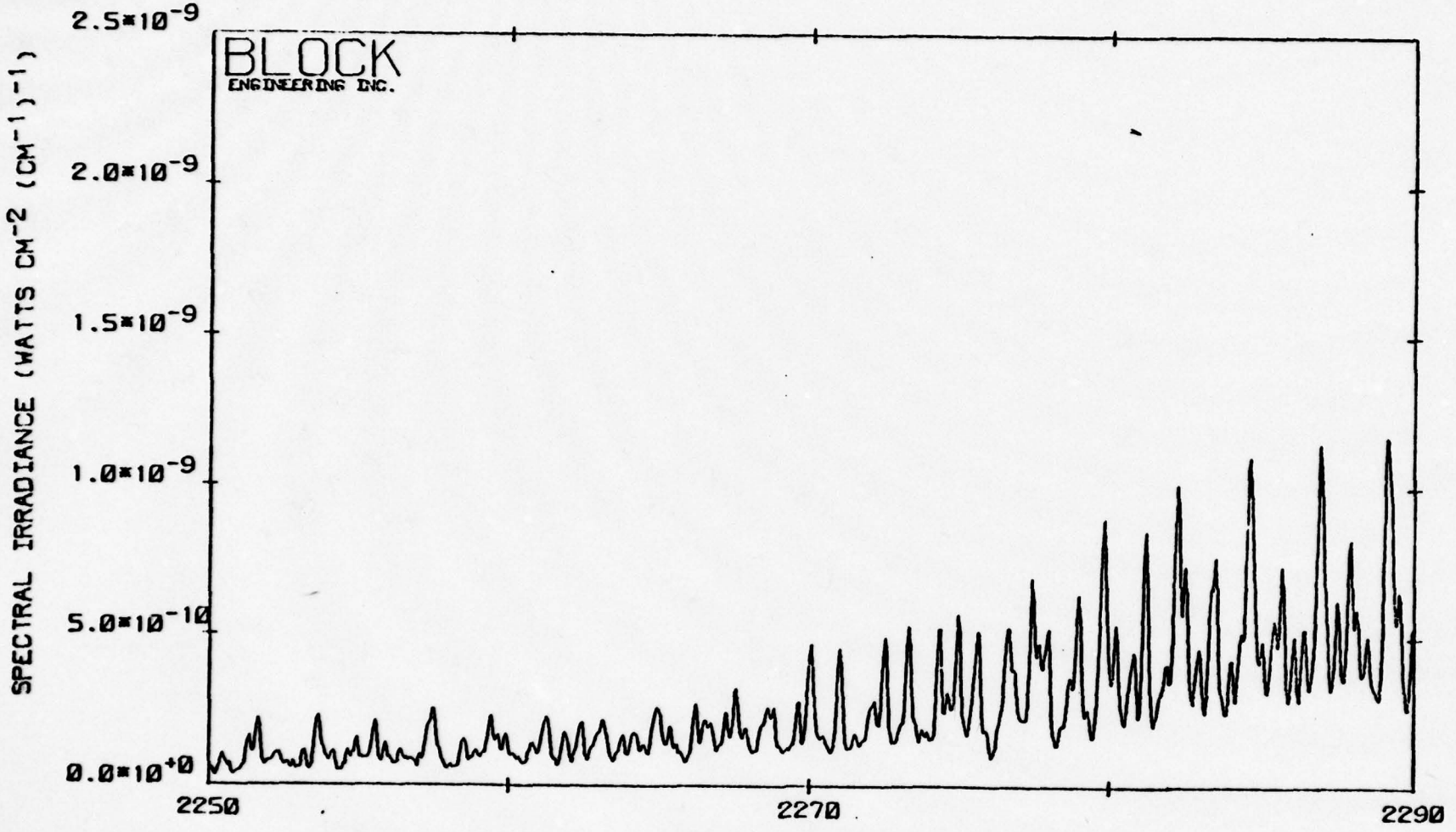

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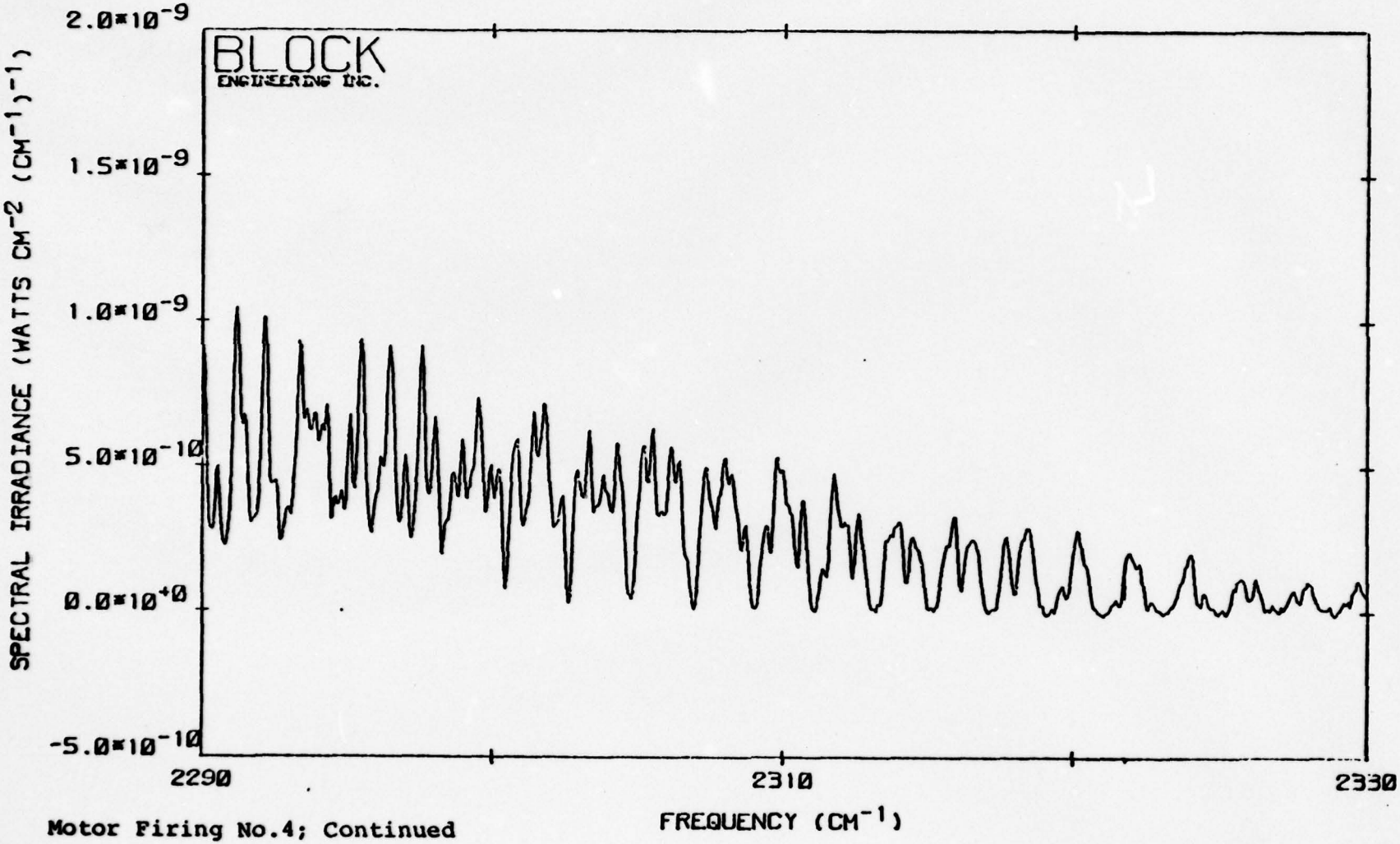

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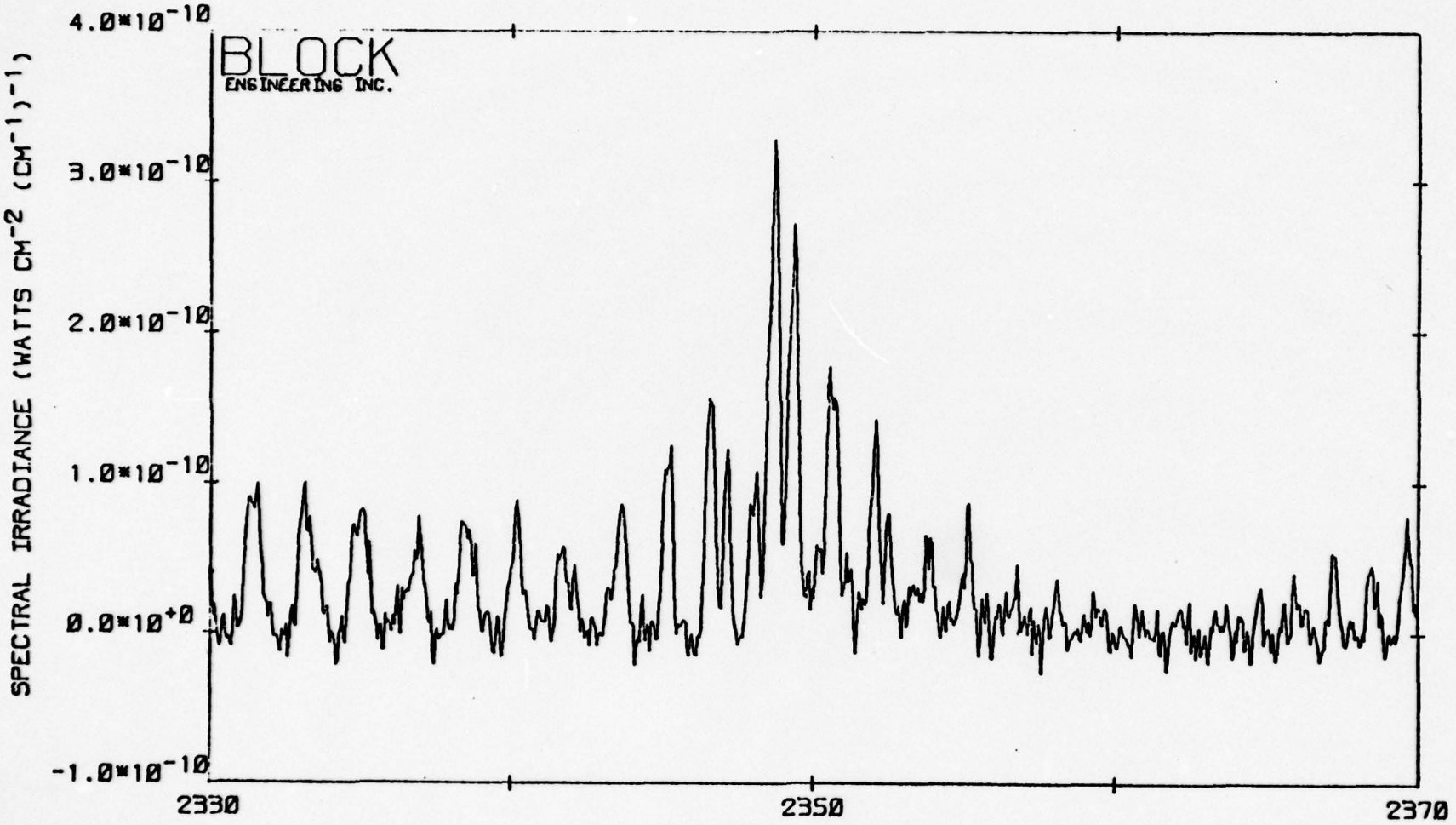

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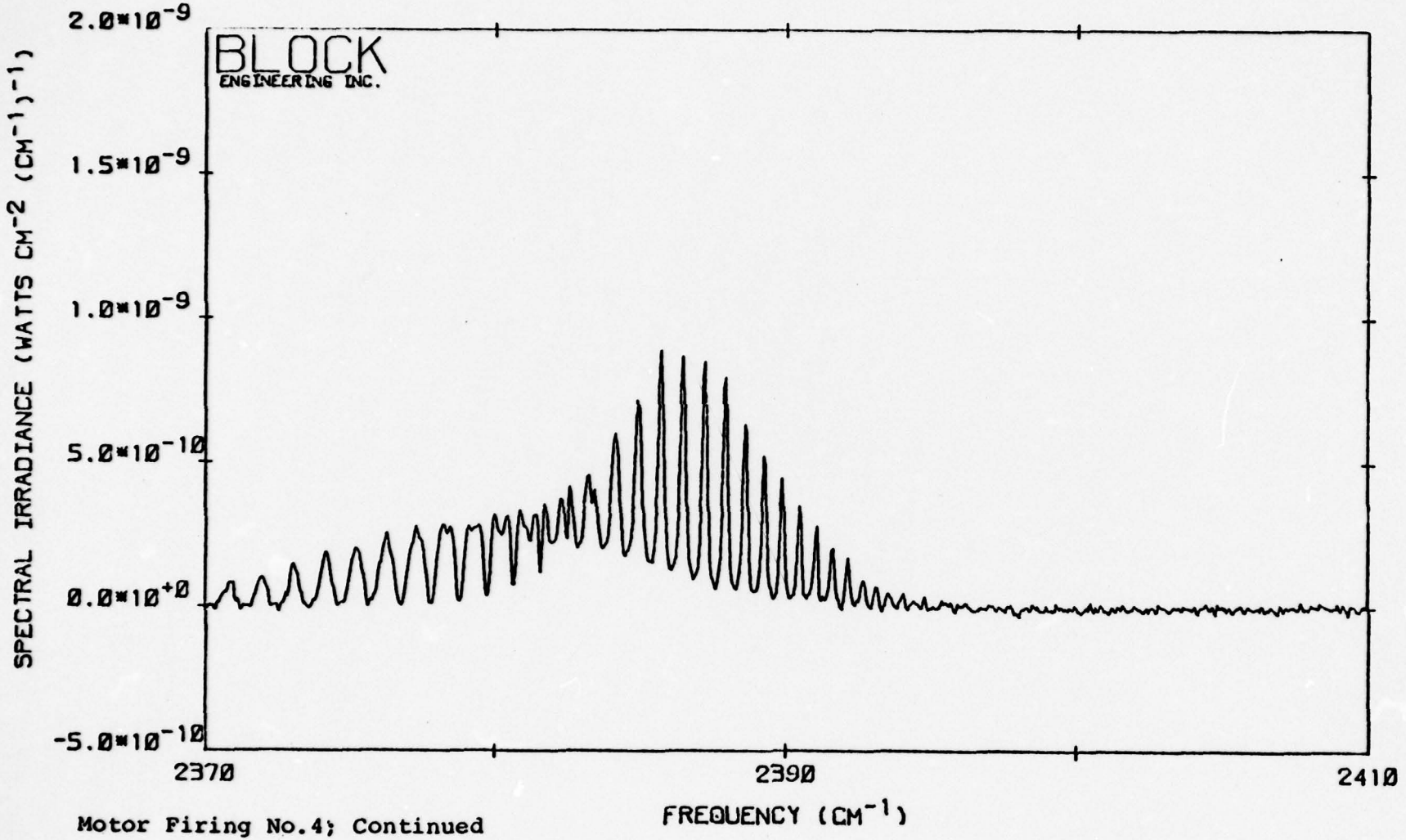

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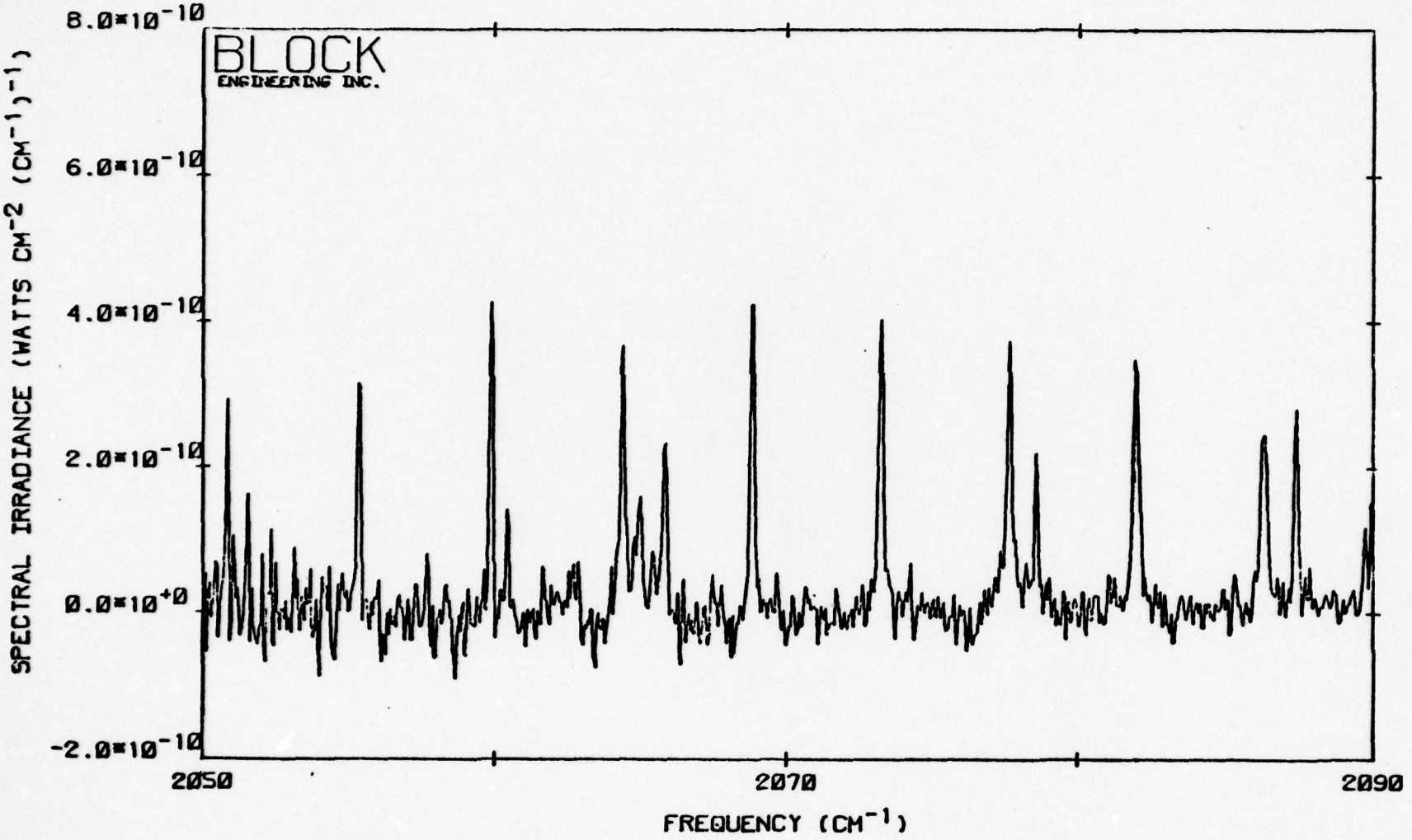
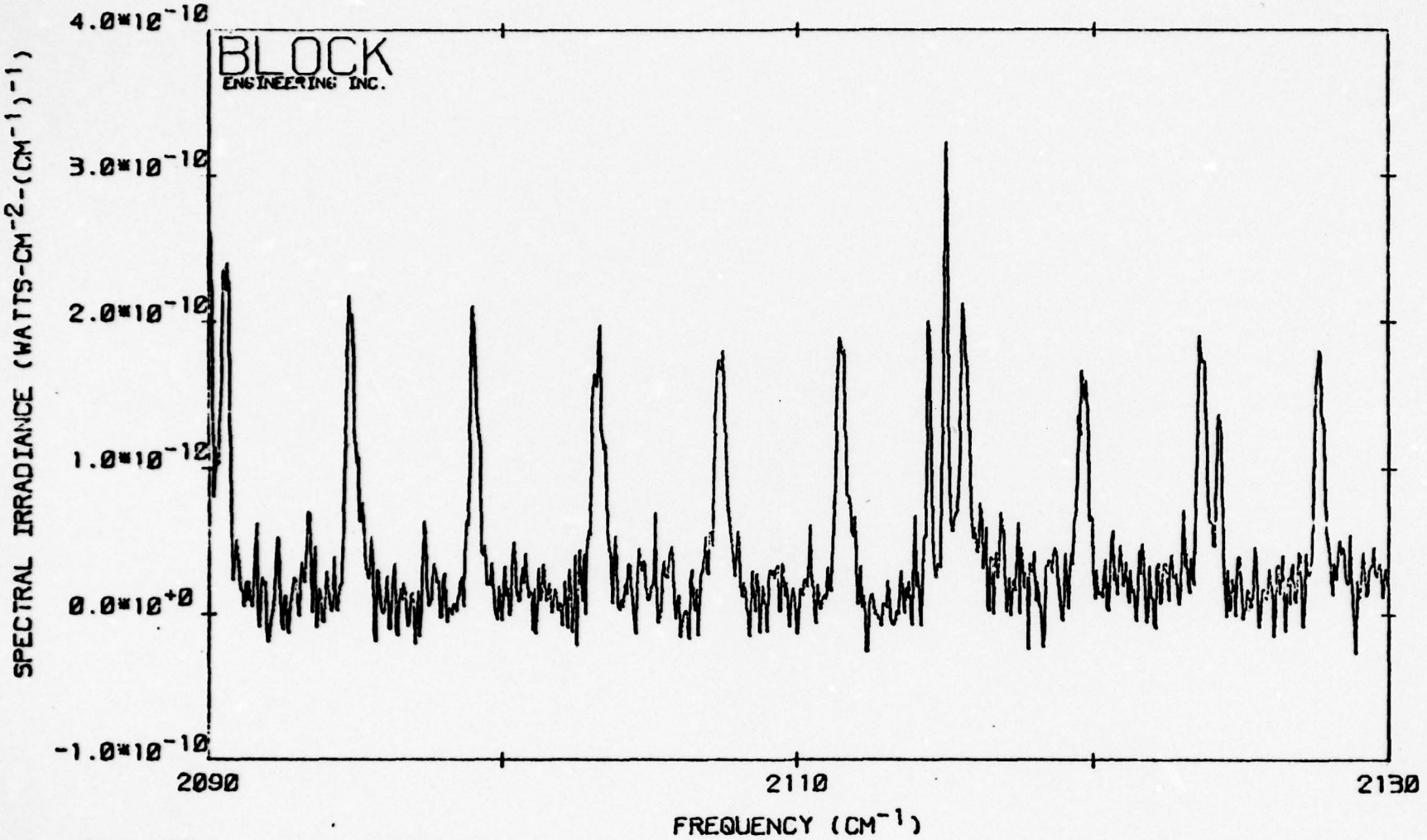


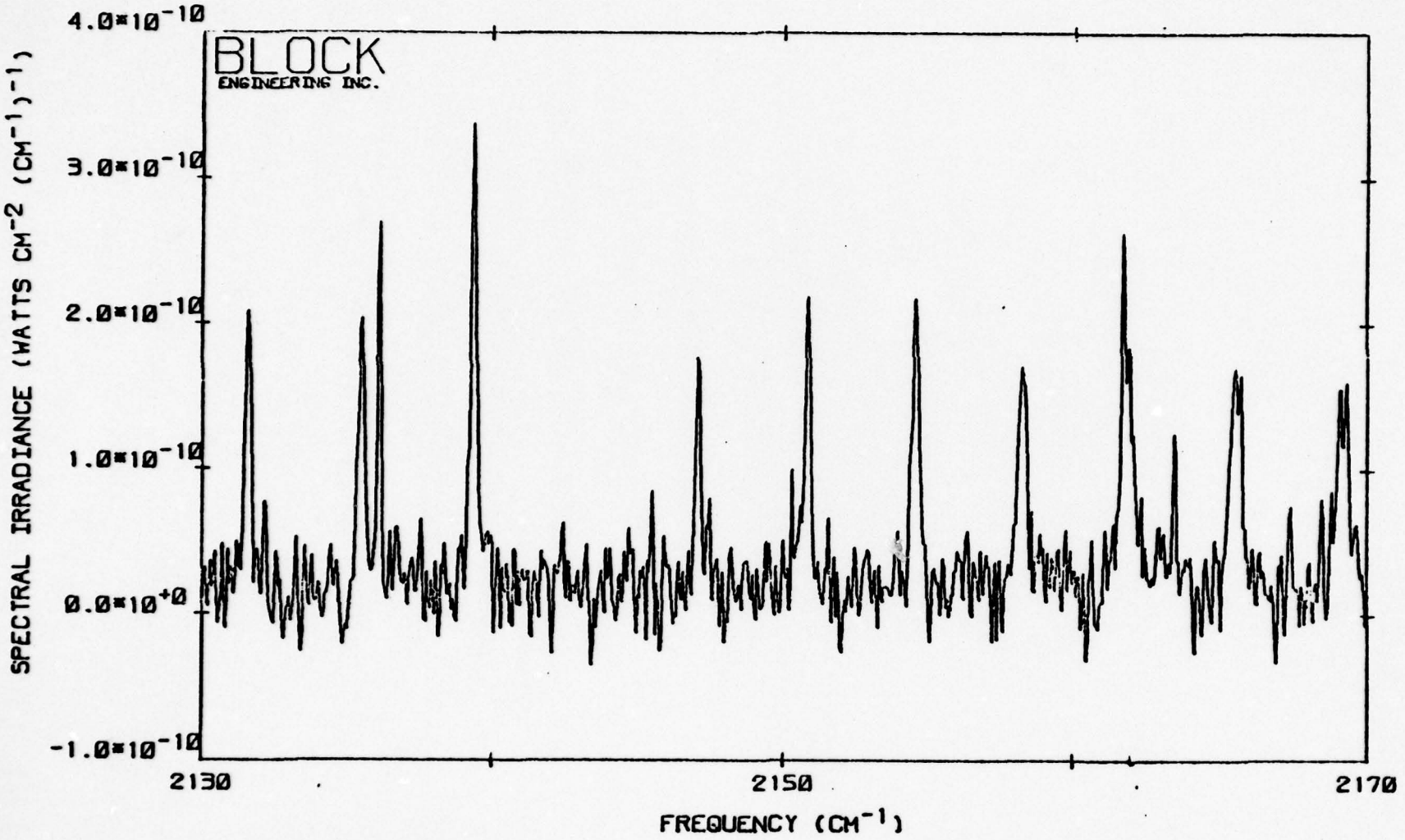
Motor Firing No.5; 4.57 km Altitude; 35 cm From Exit Plane

HF S

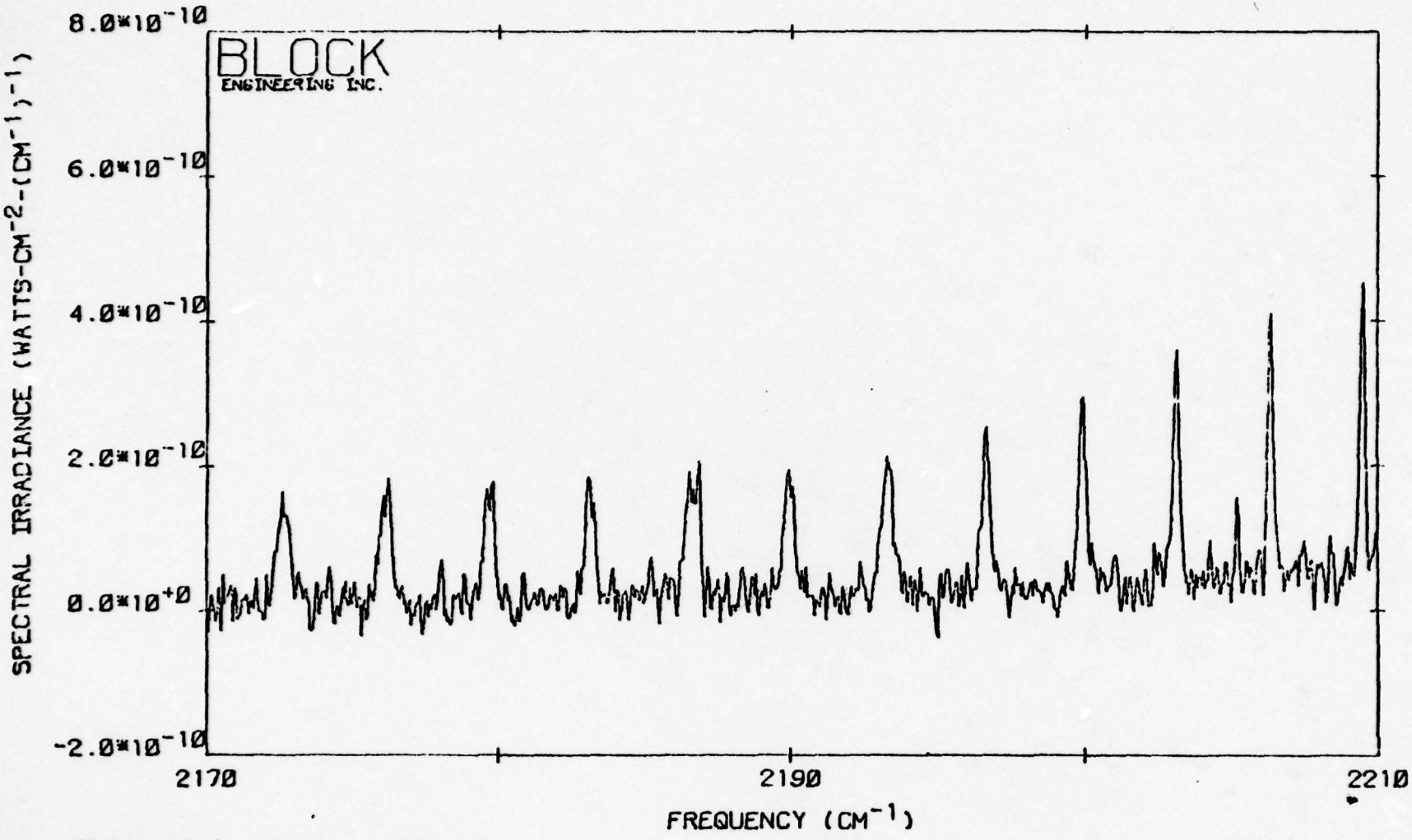


Motor Firing No.5; Continued

VF 5

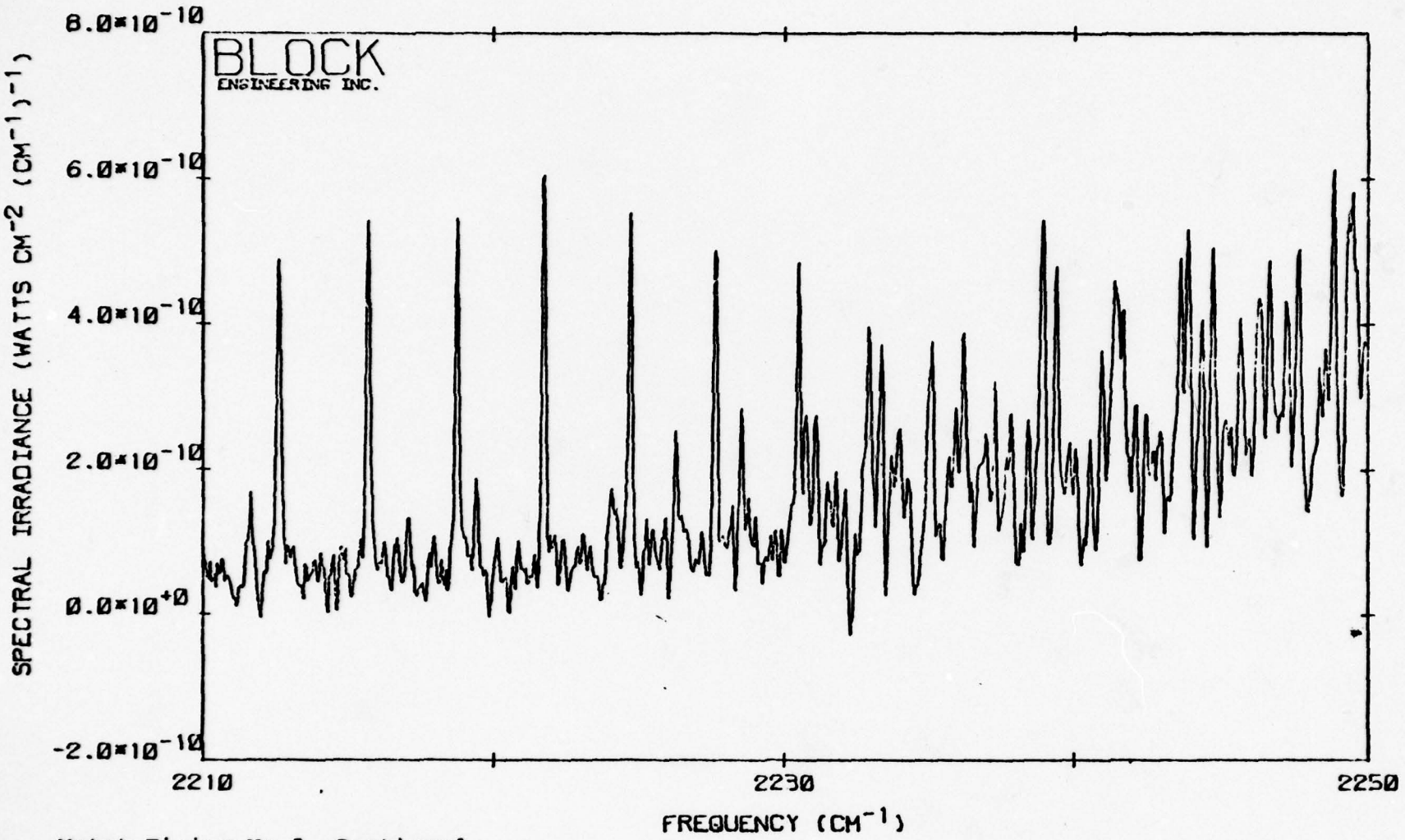


Motor Firing No.5; Continued



Motor Firing No.5; Continued

VF S



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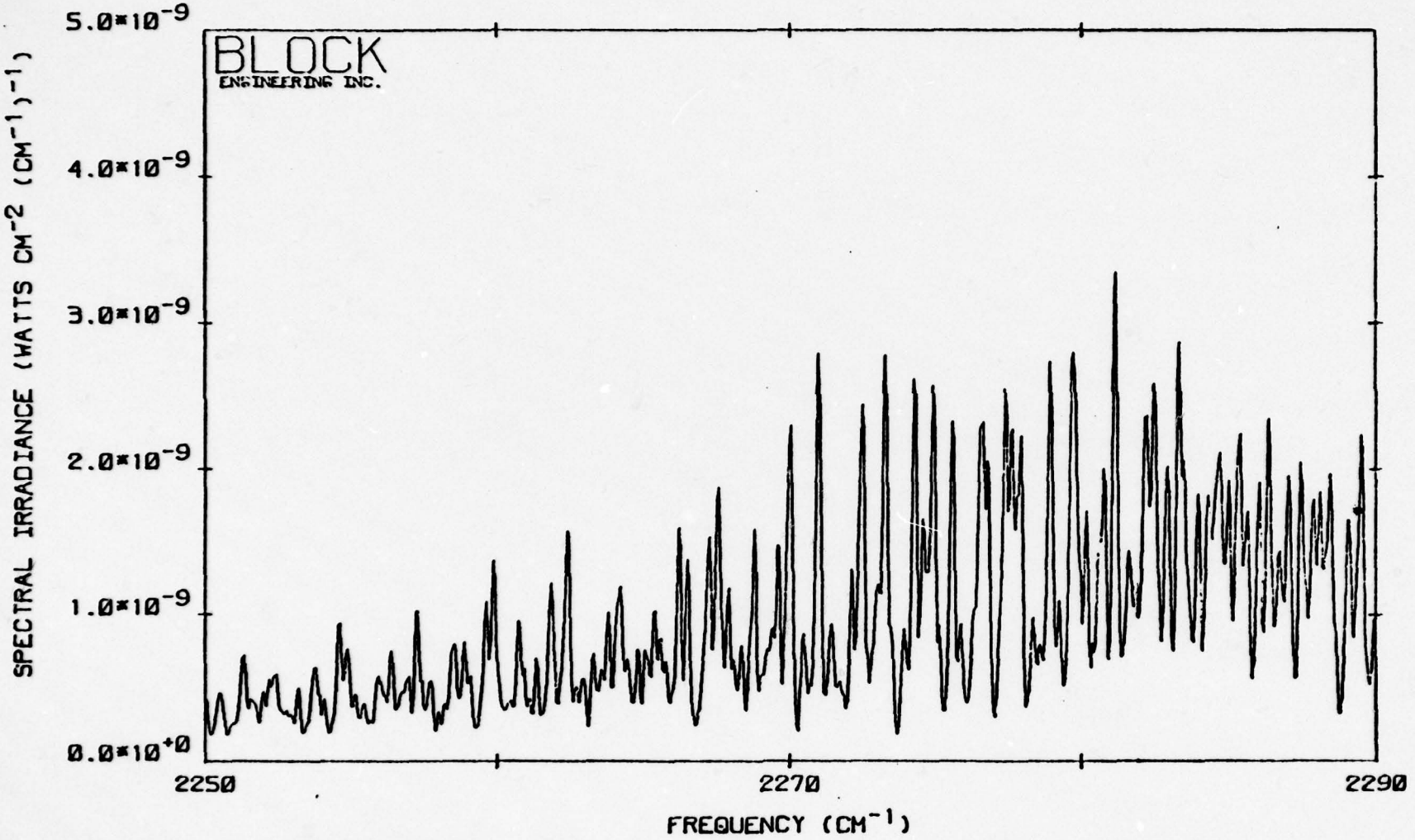
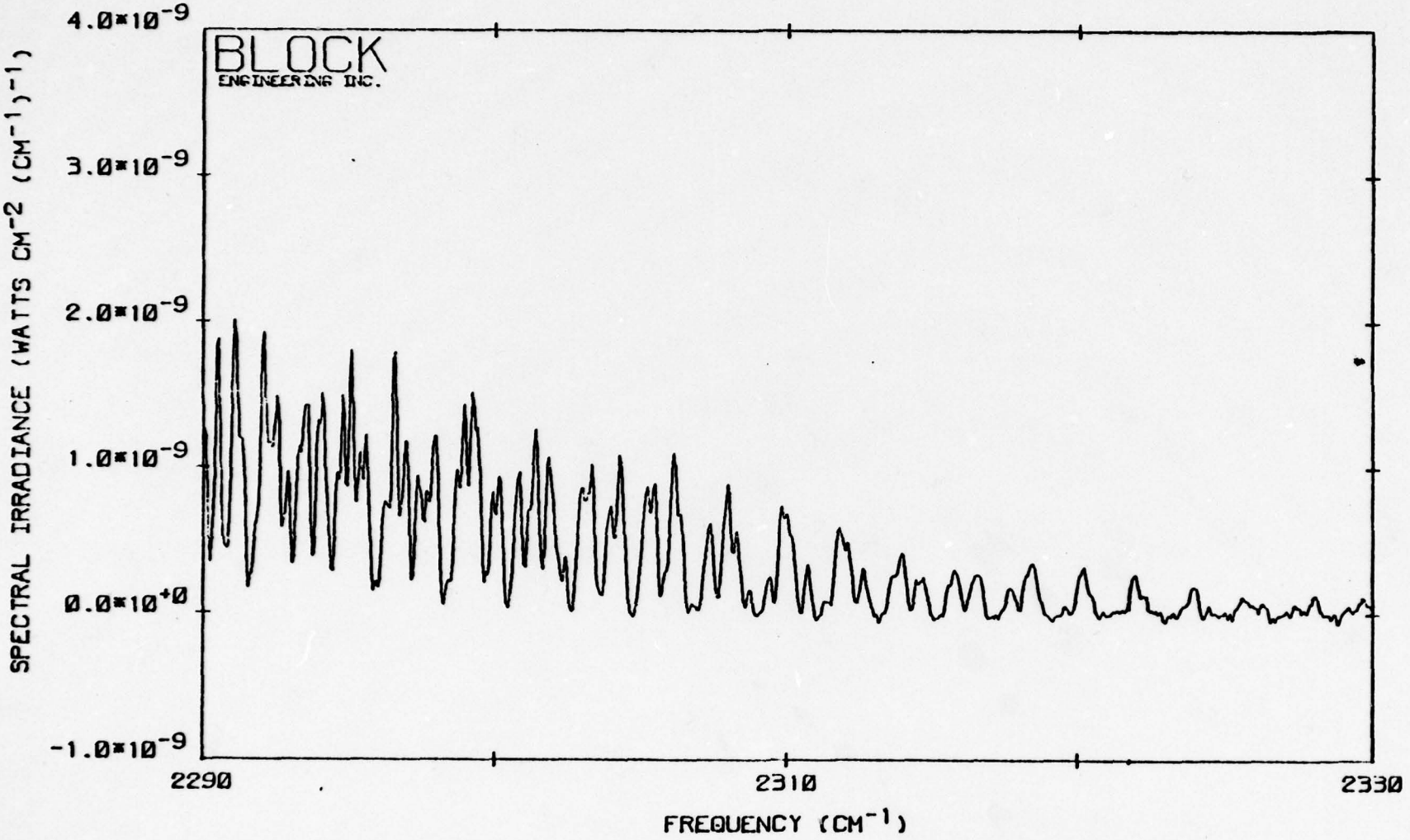
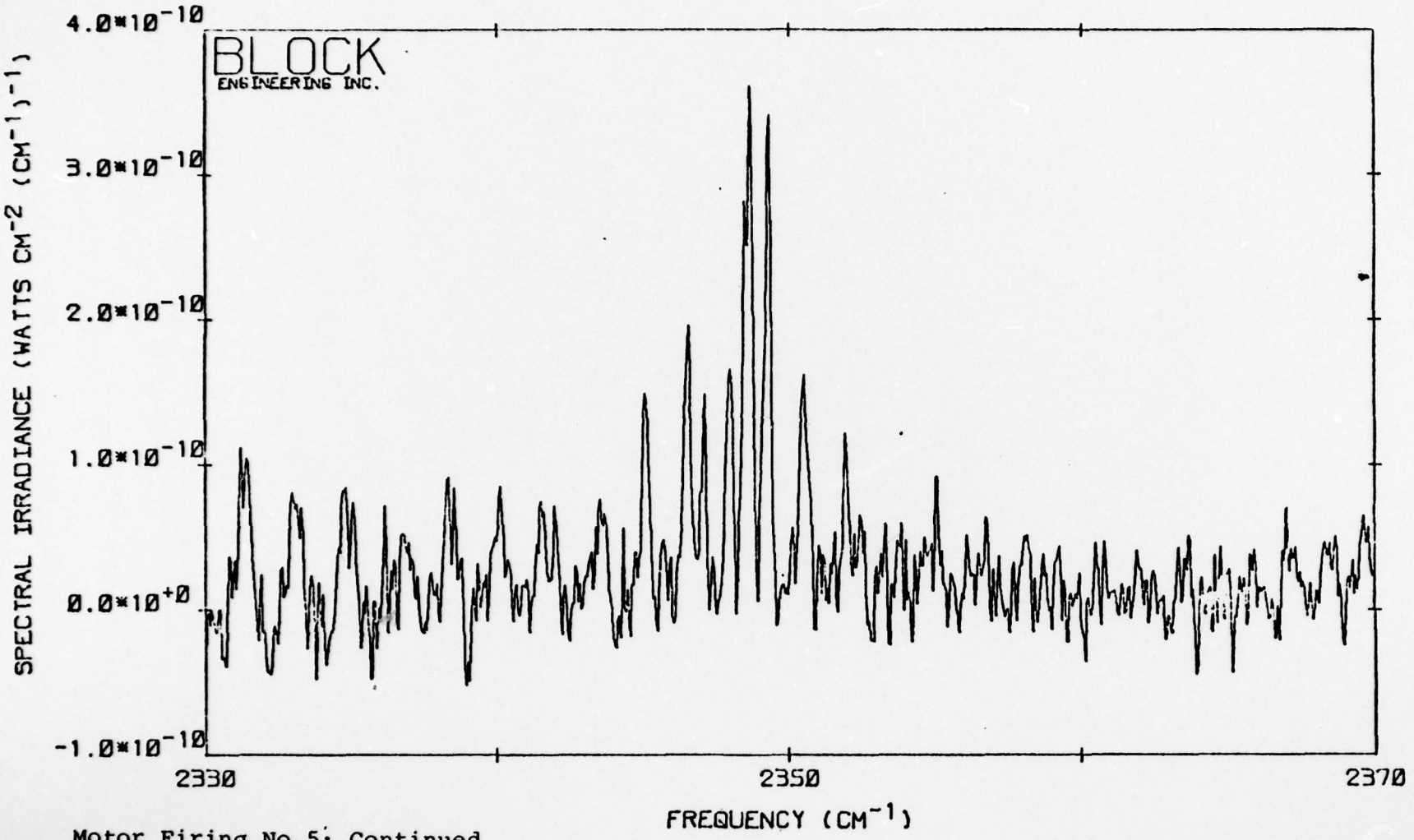


Motor Firing No.5; Continued

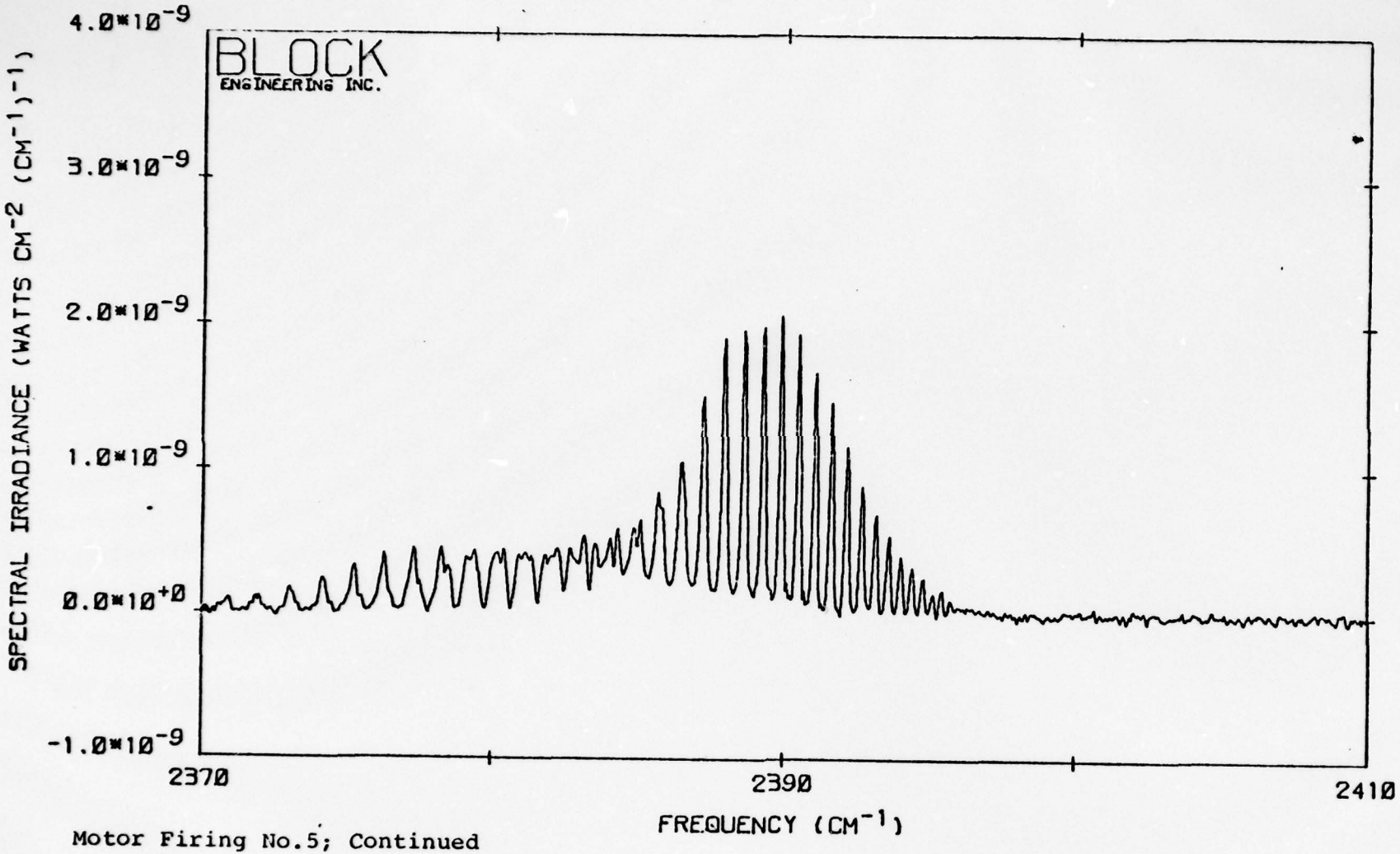


Motor Firing No.5; Continued



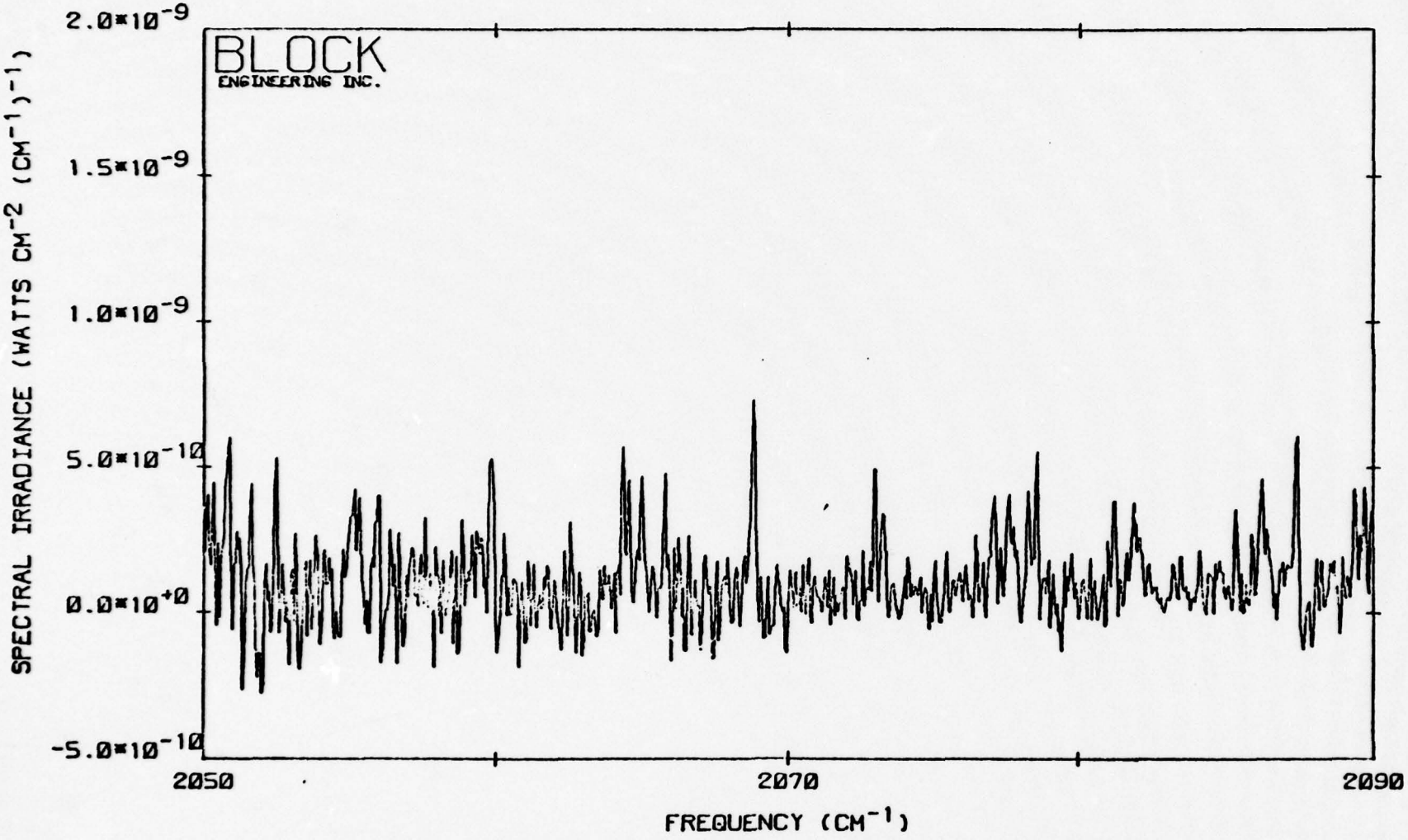
Motor Firing No.5; Continued

VF S

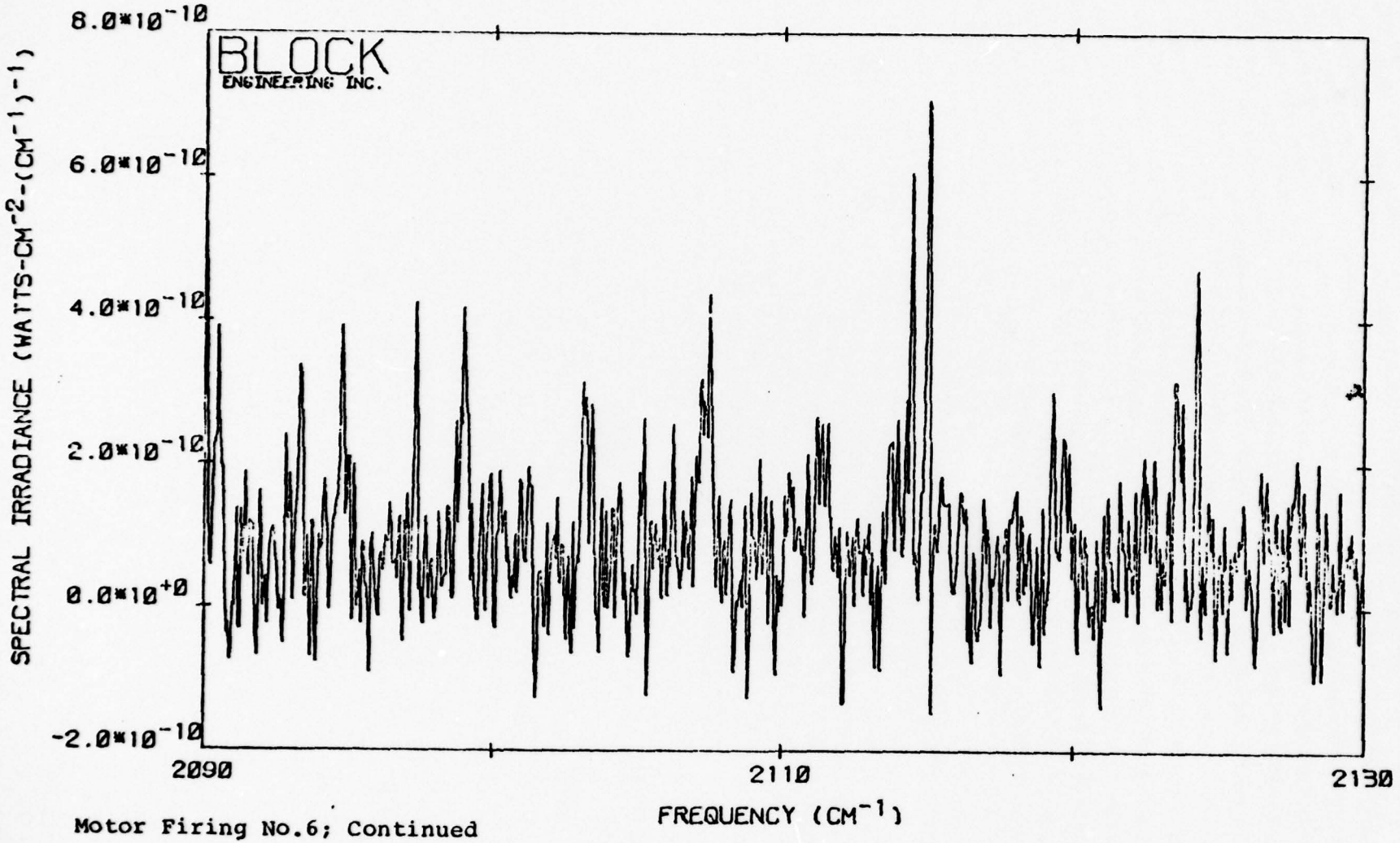


Motor Firing No.5; Continued

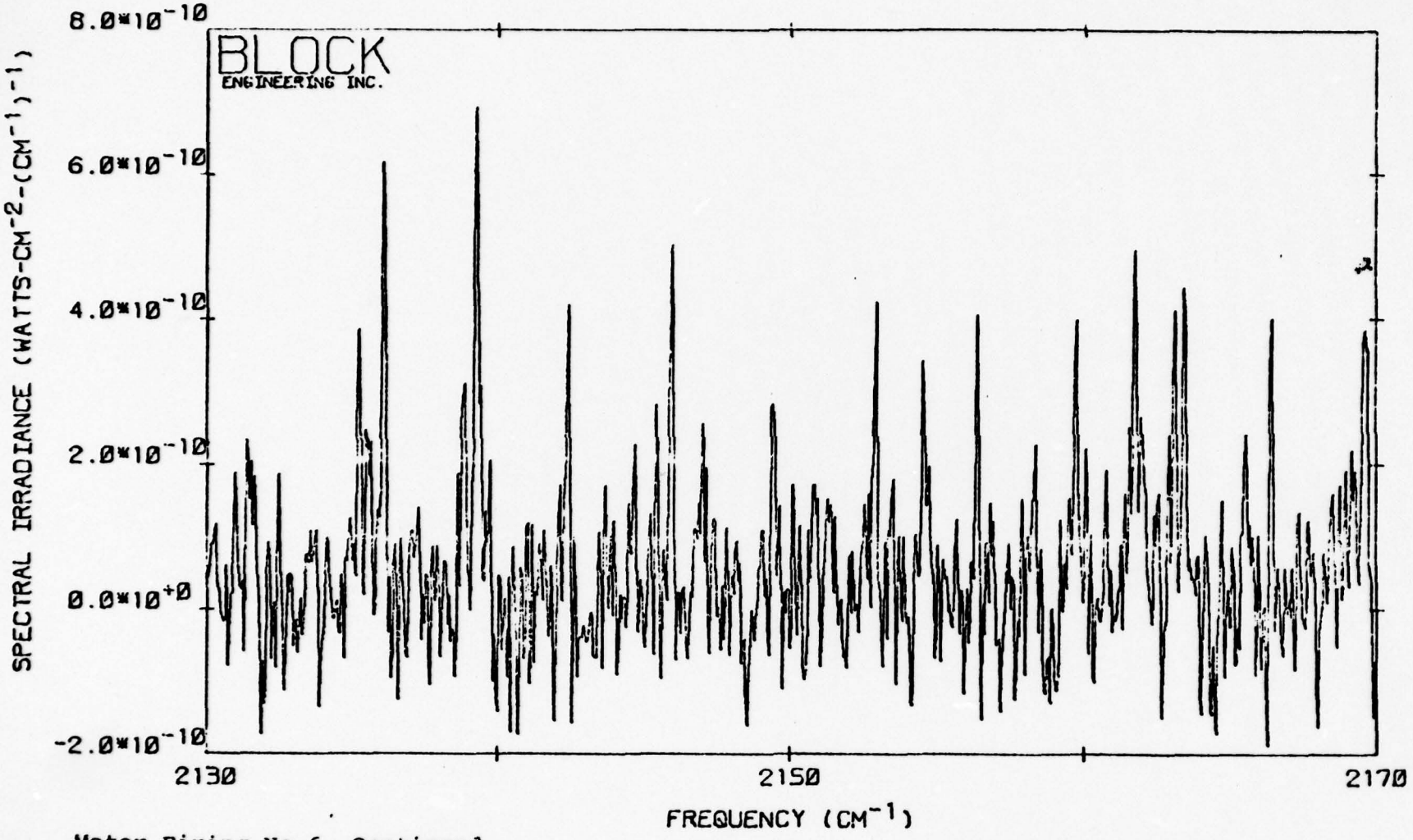
VF 5



Motor Firing No.6; 12.19 km Altitude; 35 cm From Exit Plane



Motor Firing No.6; Continued



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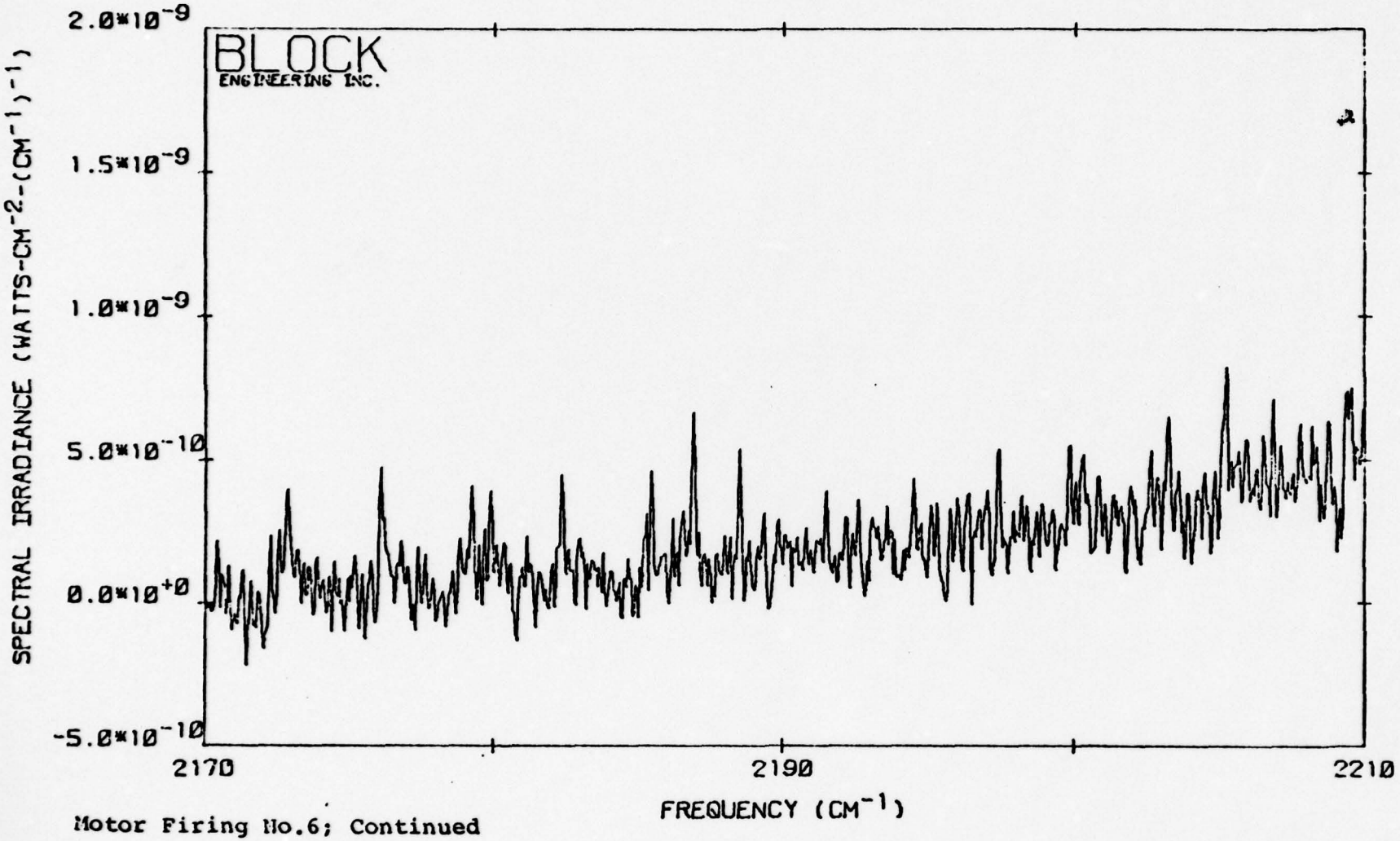

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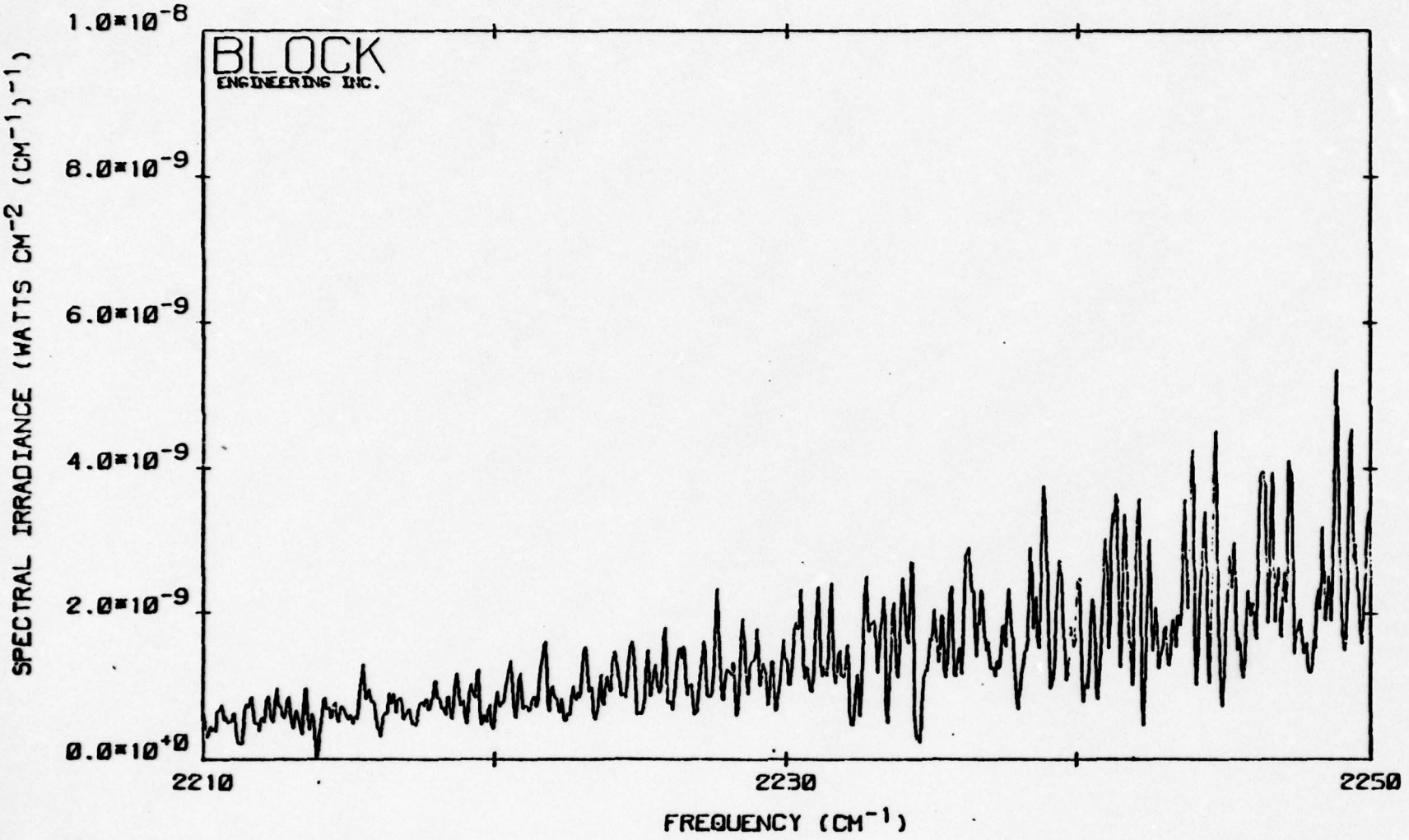

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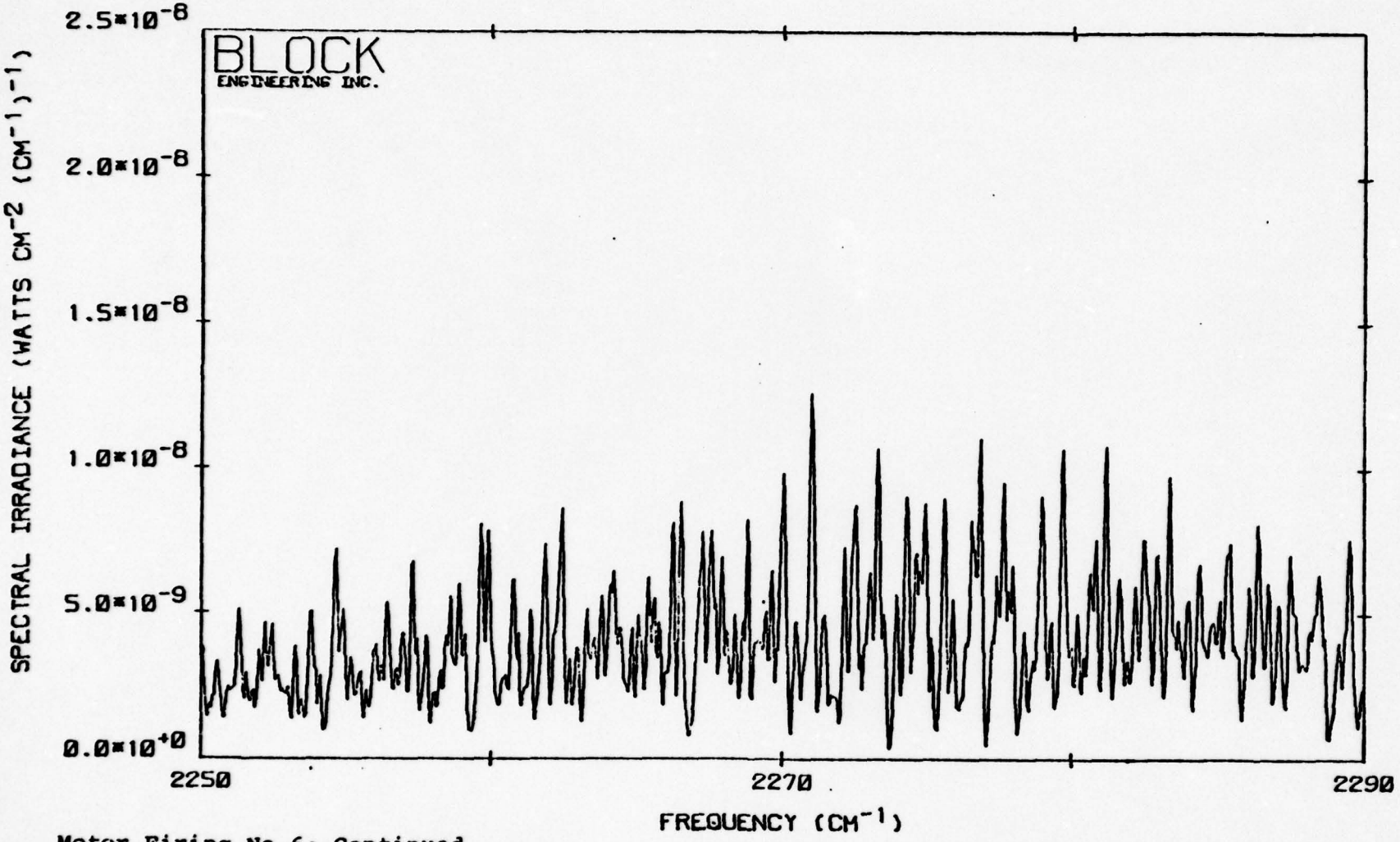

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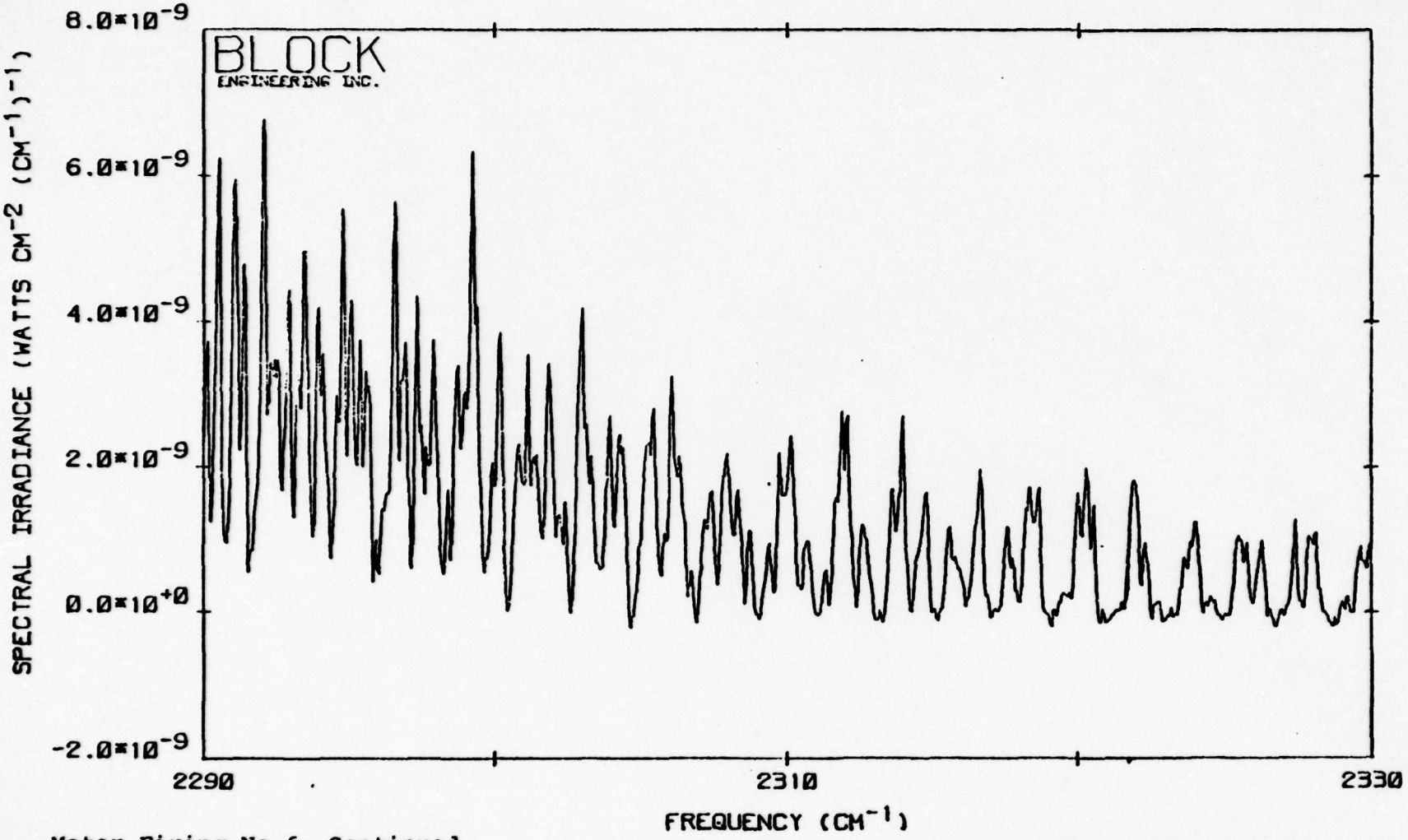

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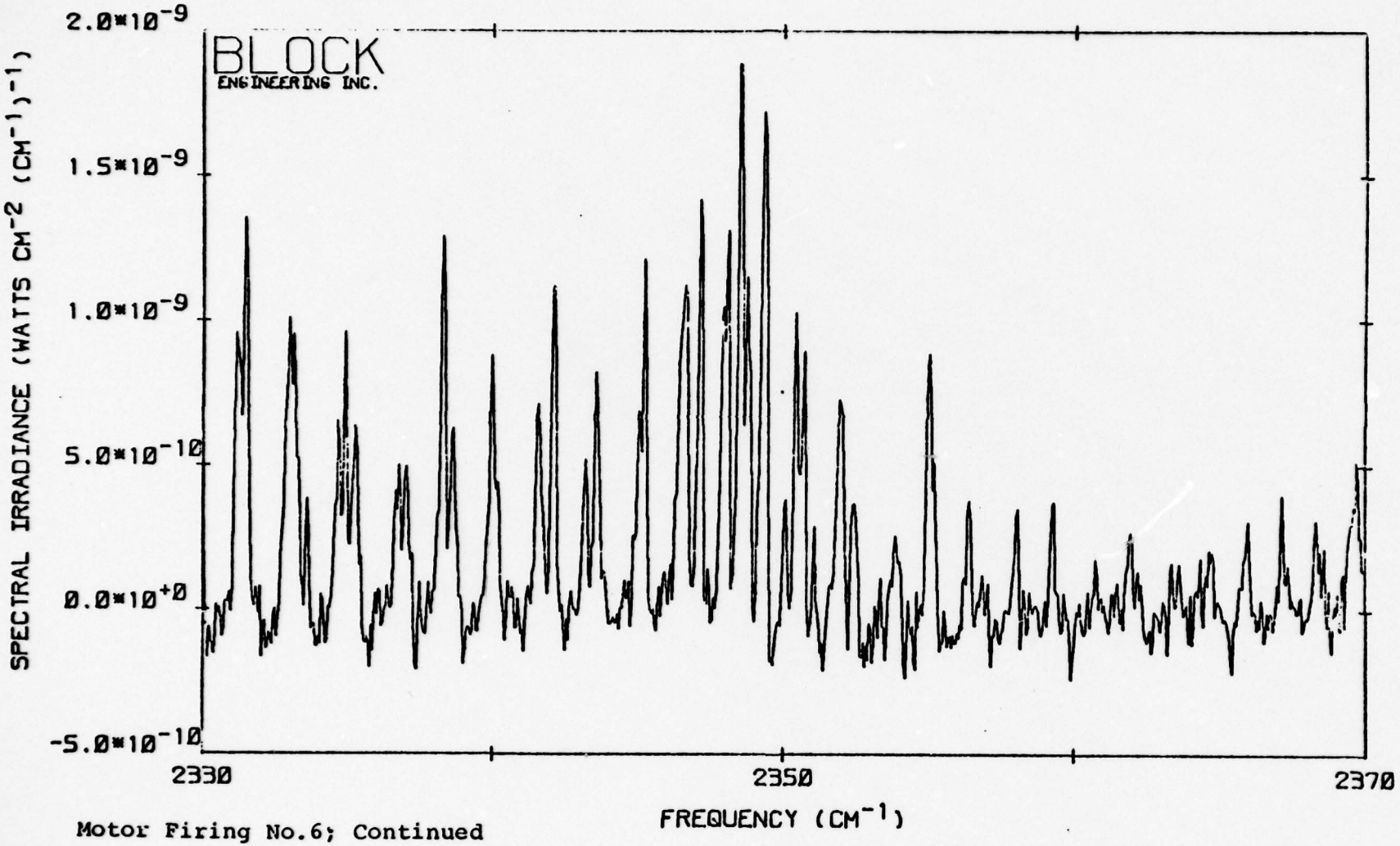

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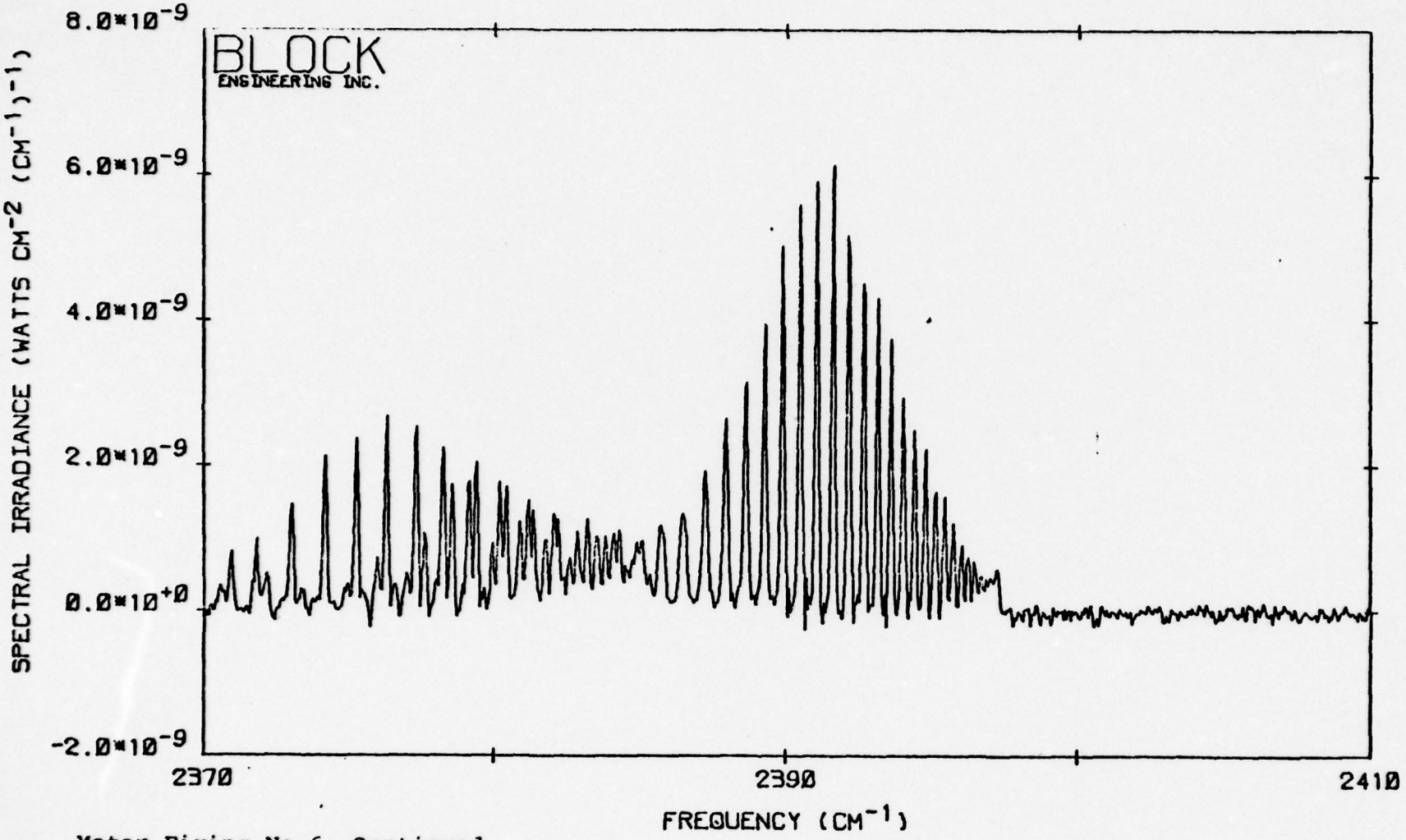
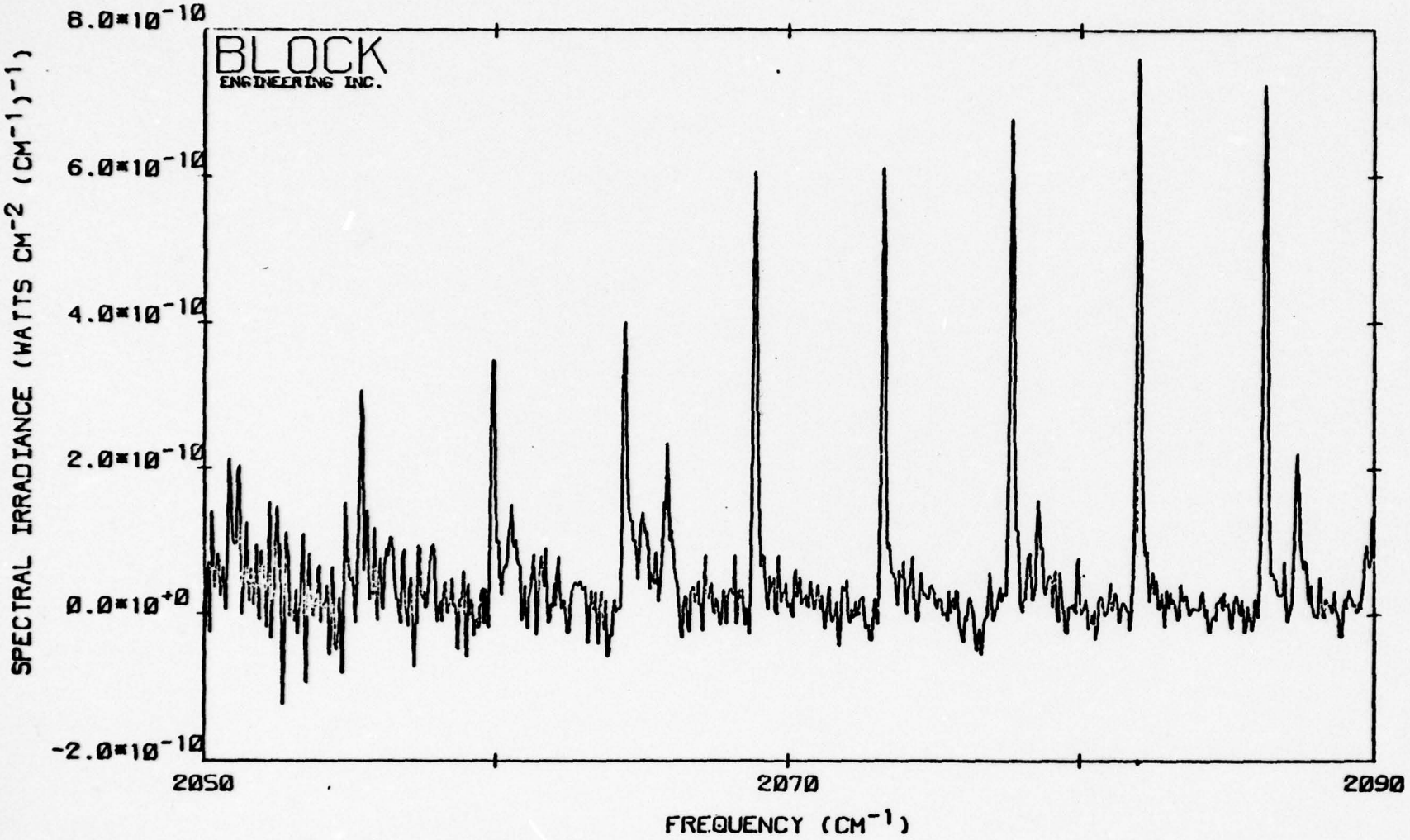
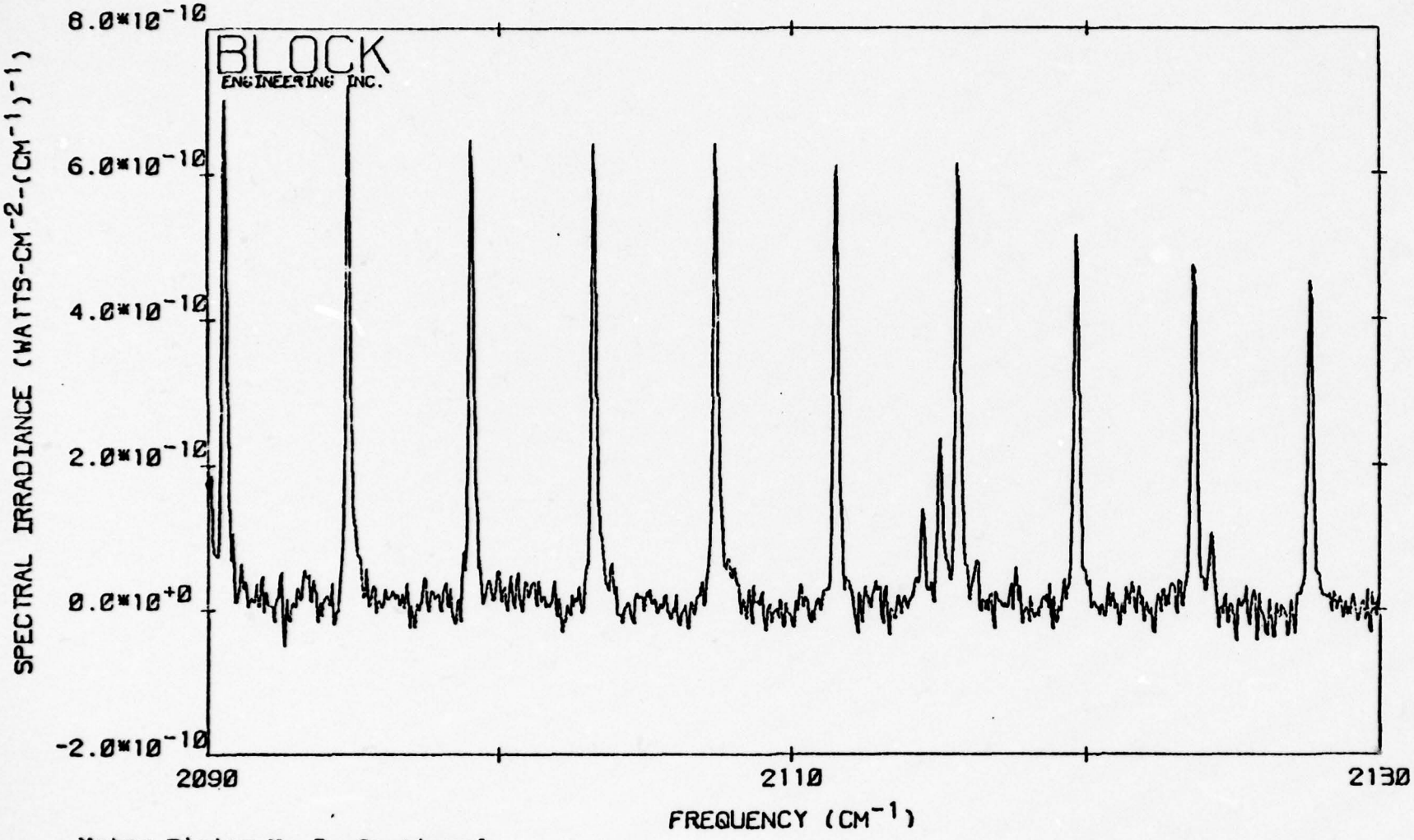


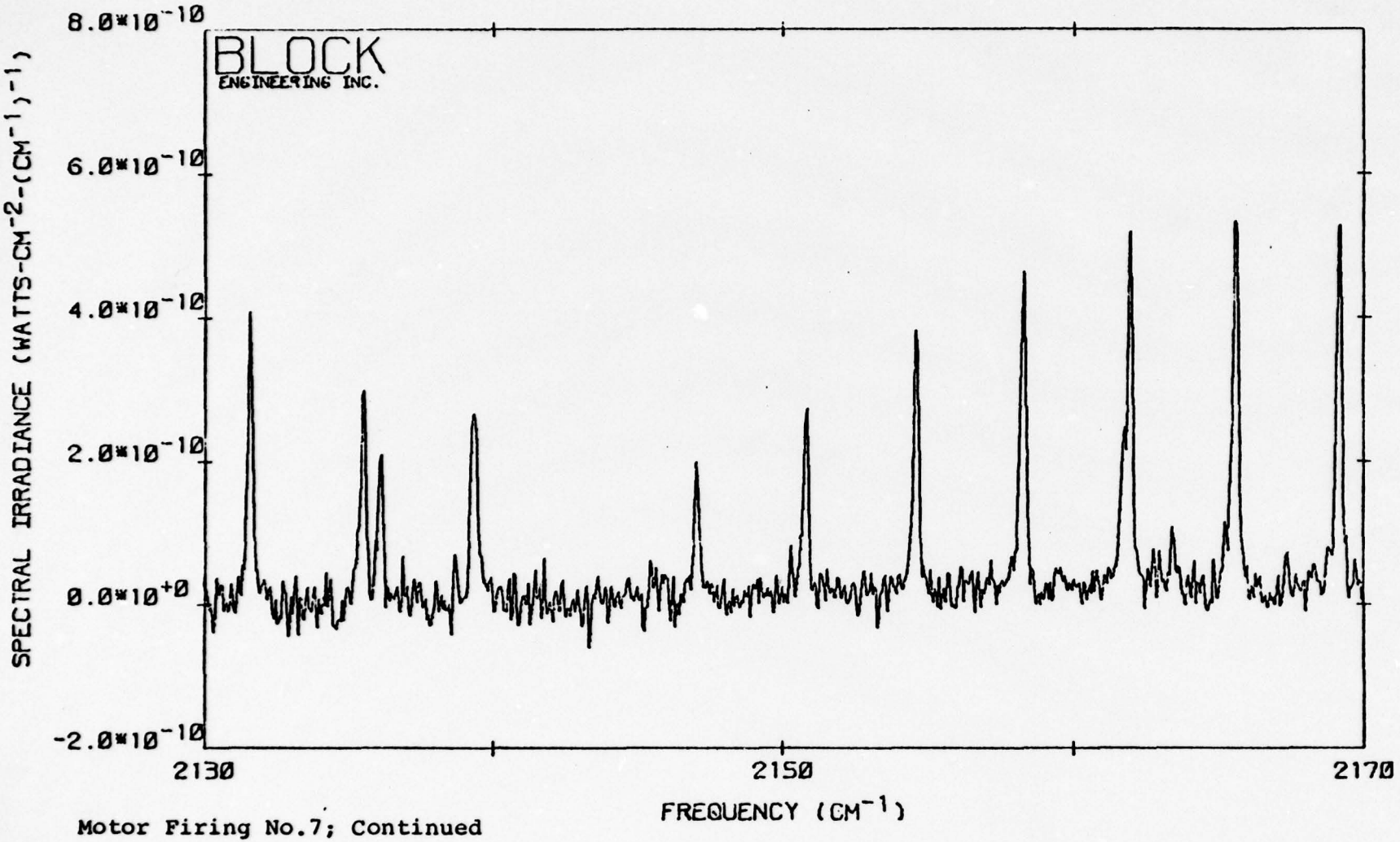
Motor Firing No.6; Continued



Motor Firing No.7; 0 km Altitude; 25 cm From Exit Plane



Motor Firing No.7; Continued



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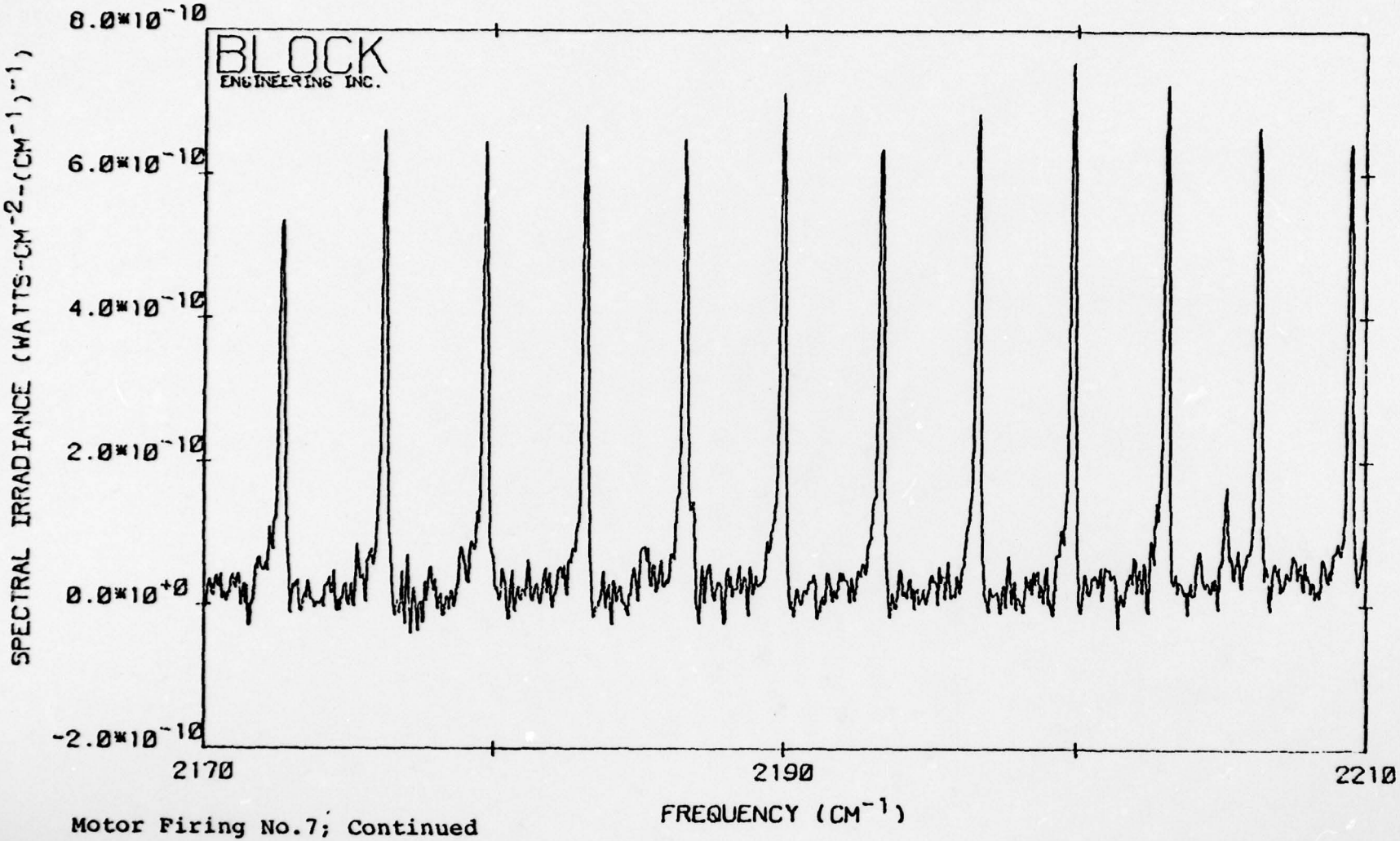

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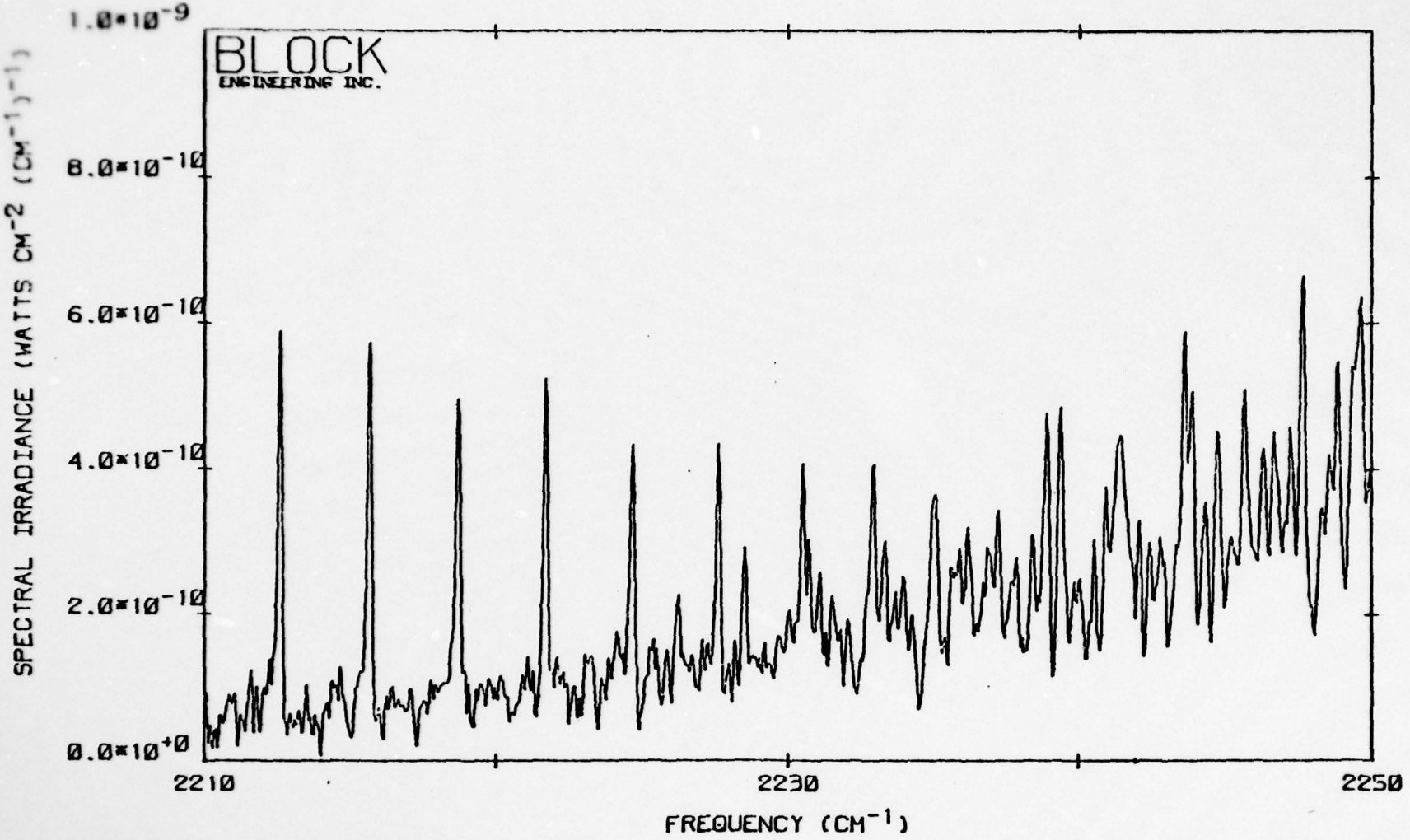

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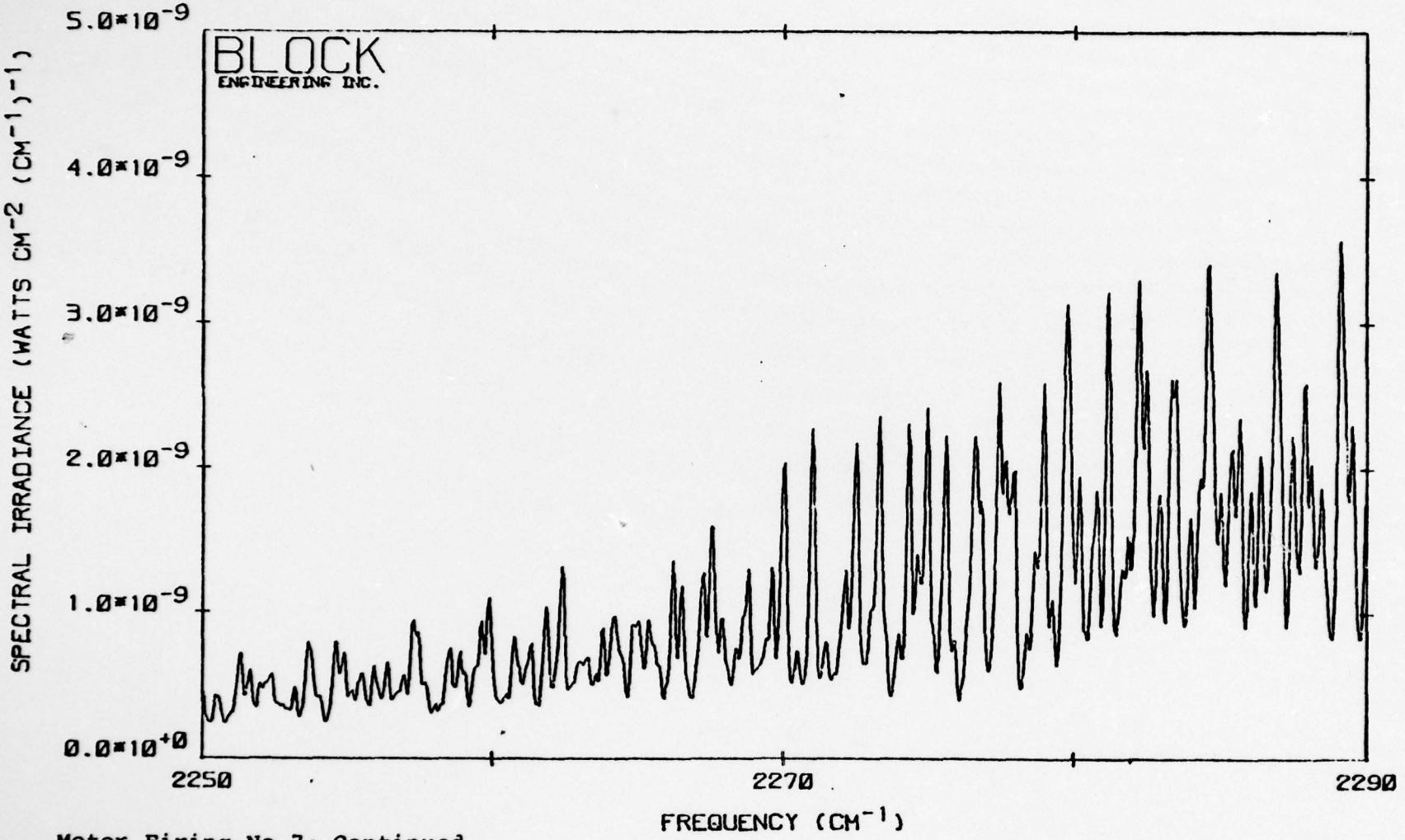

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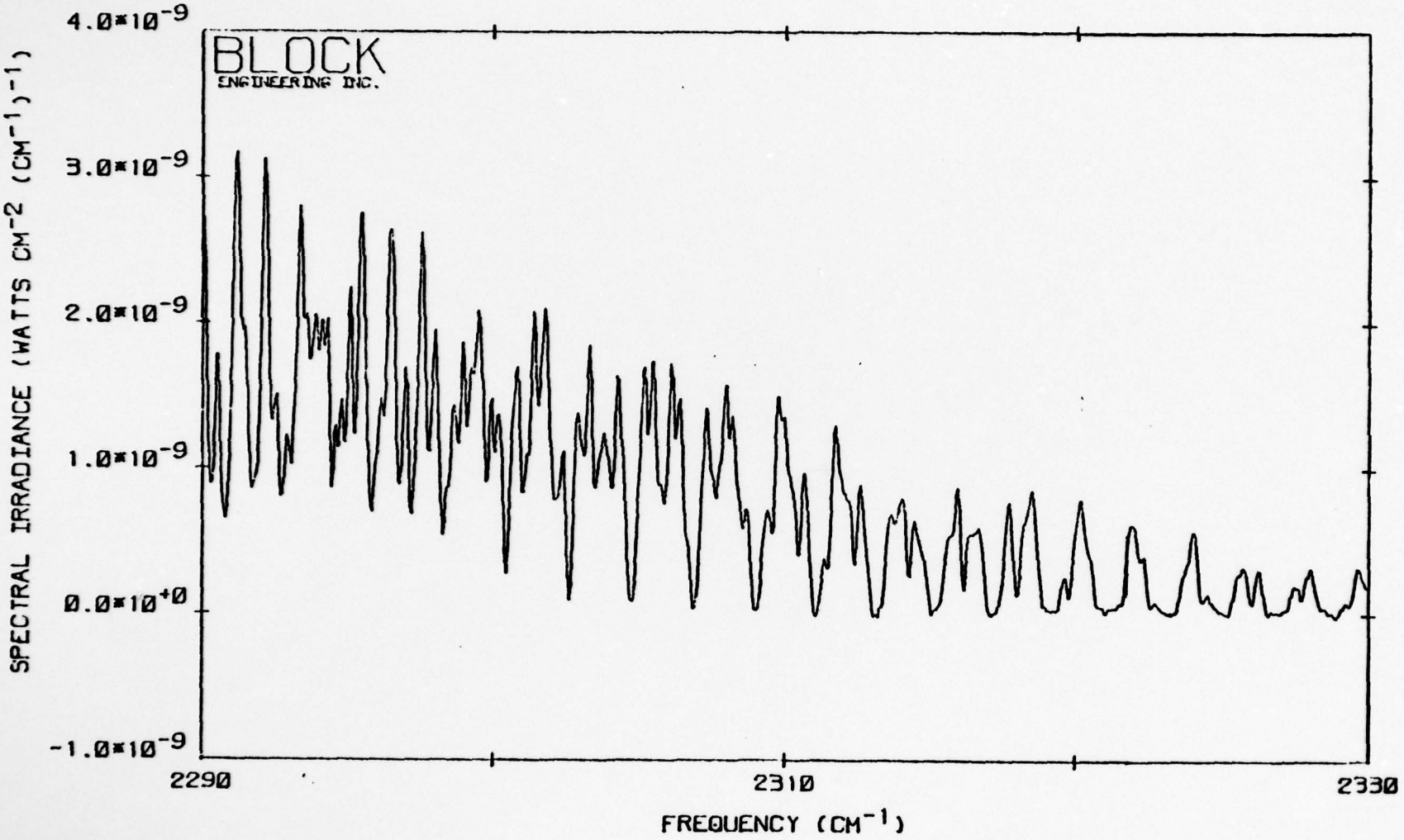

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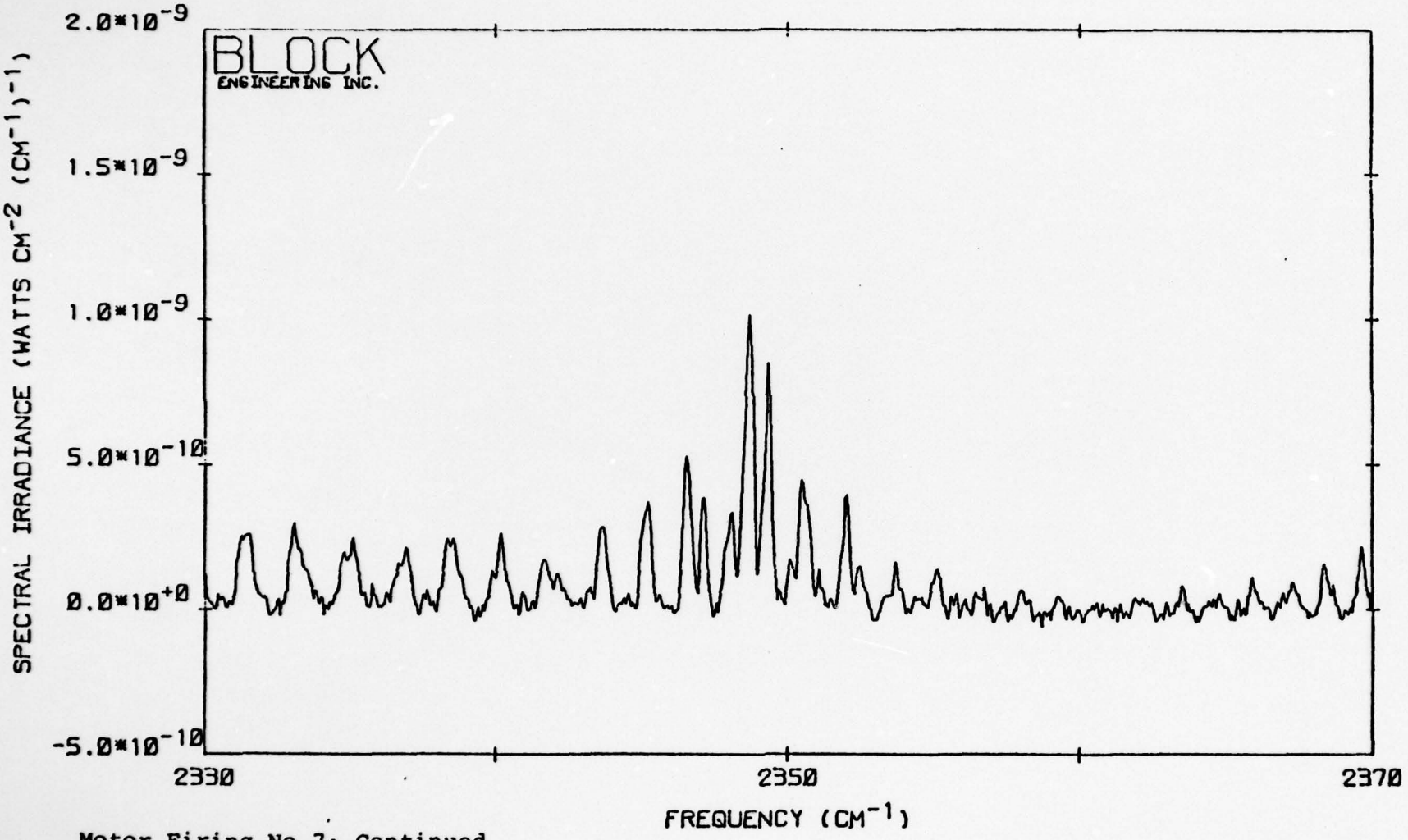

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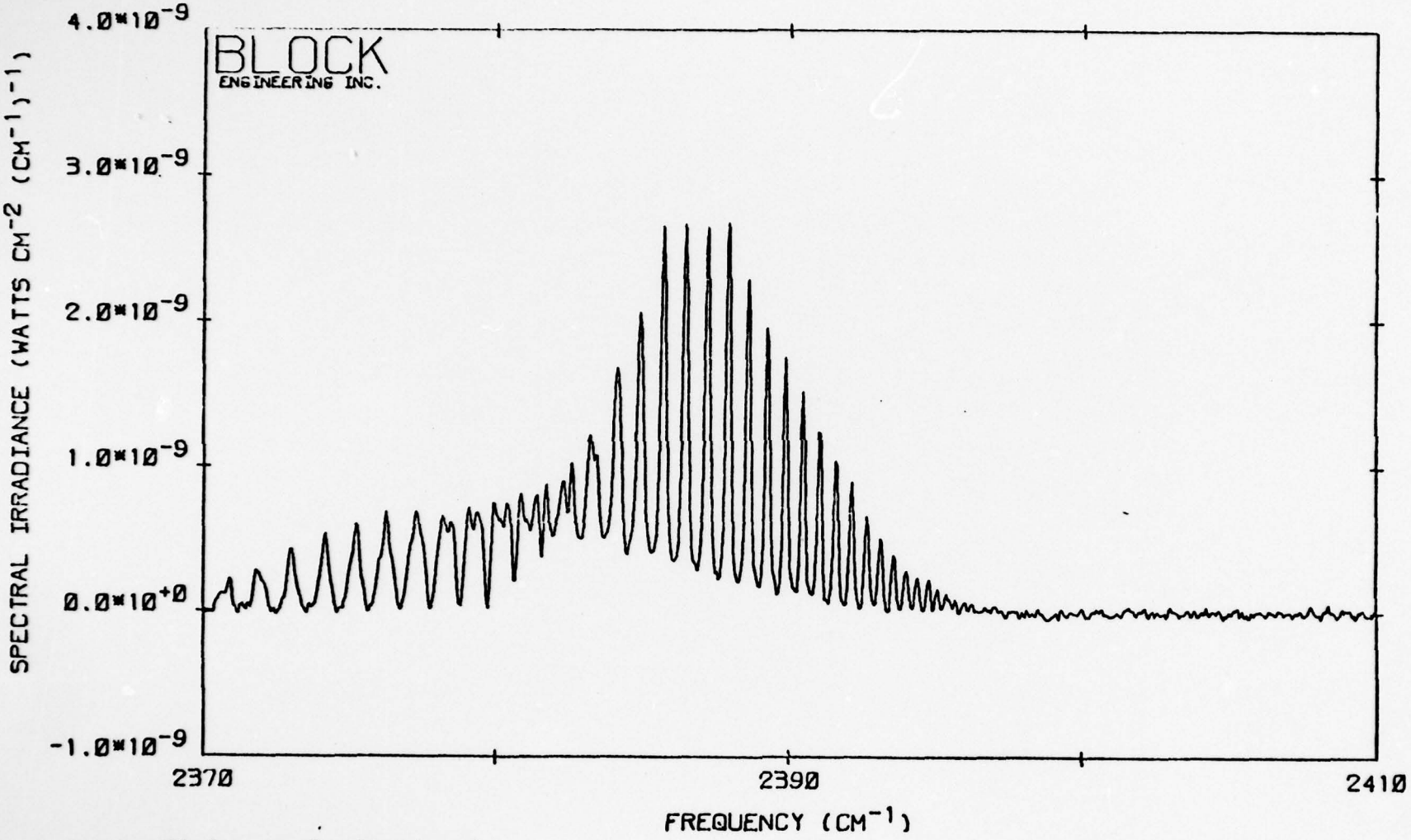

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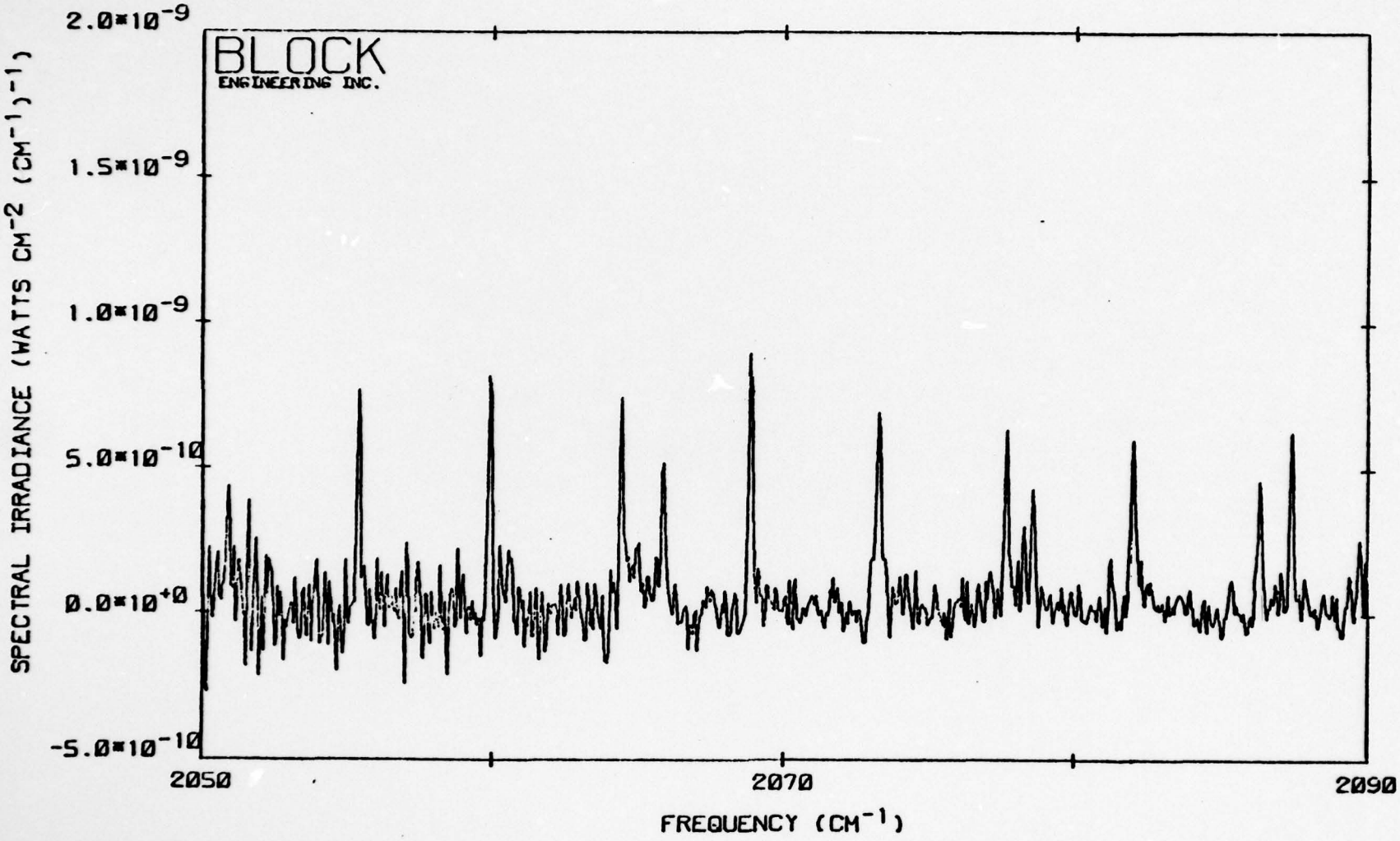
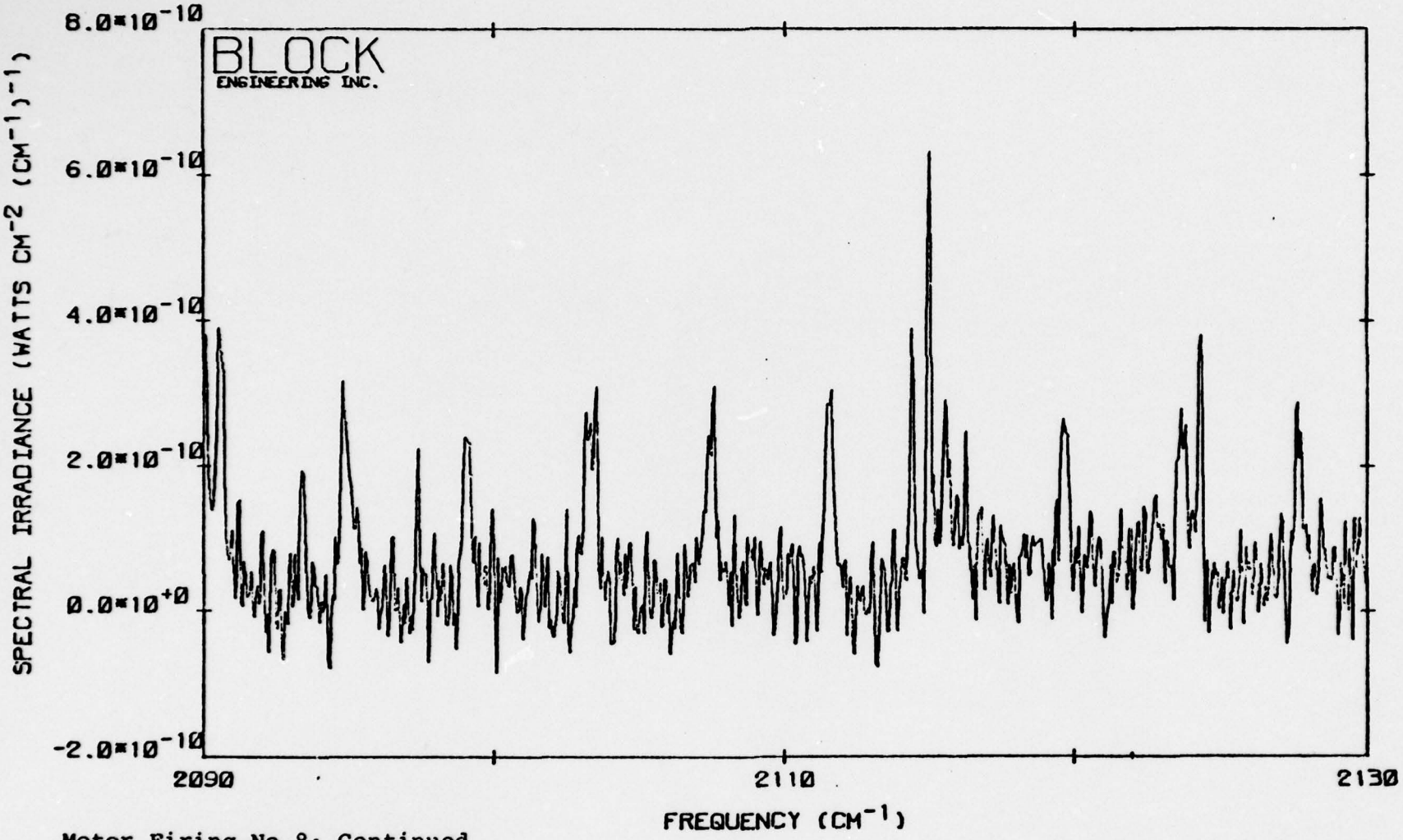


Motor Firing No.8; 4.57 km Altitude; 25 cm From Exit Plane



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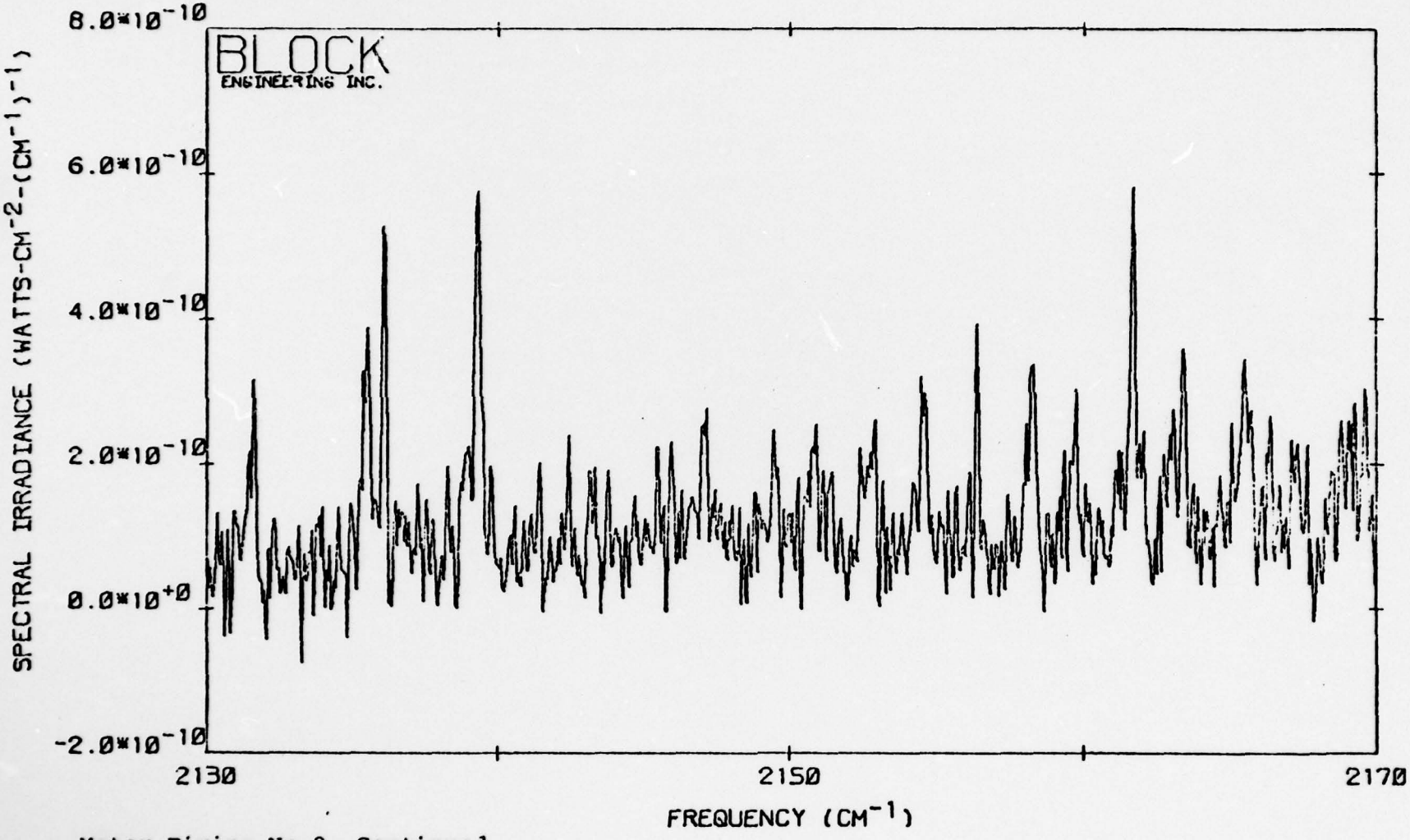

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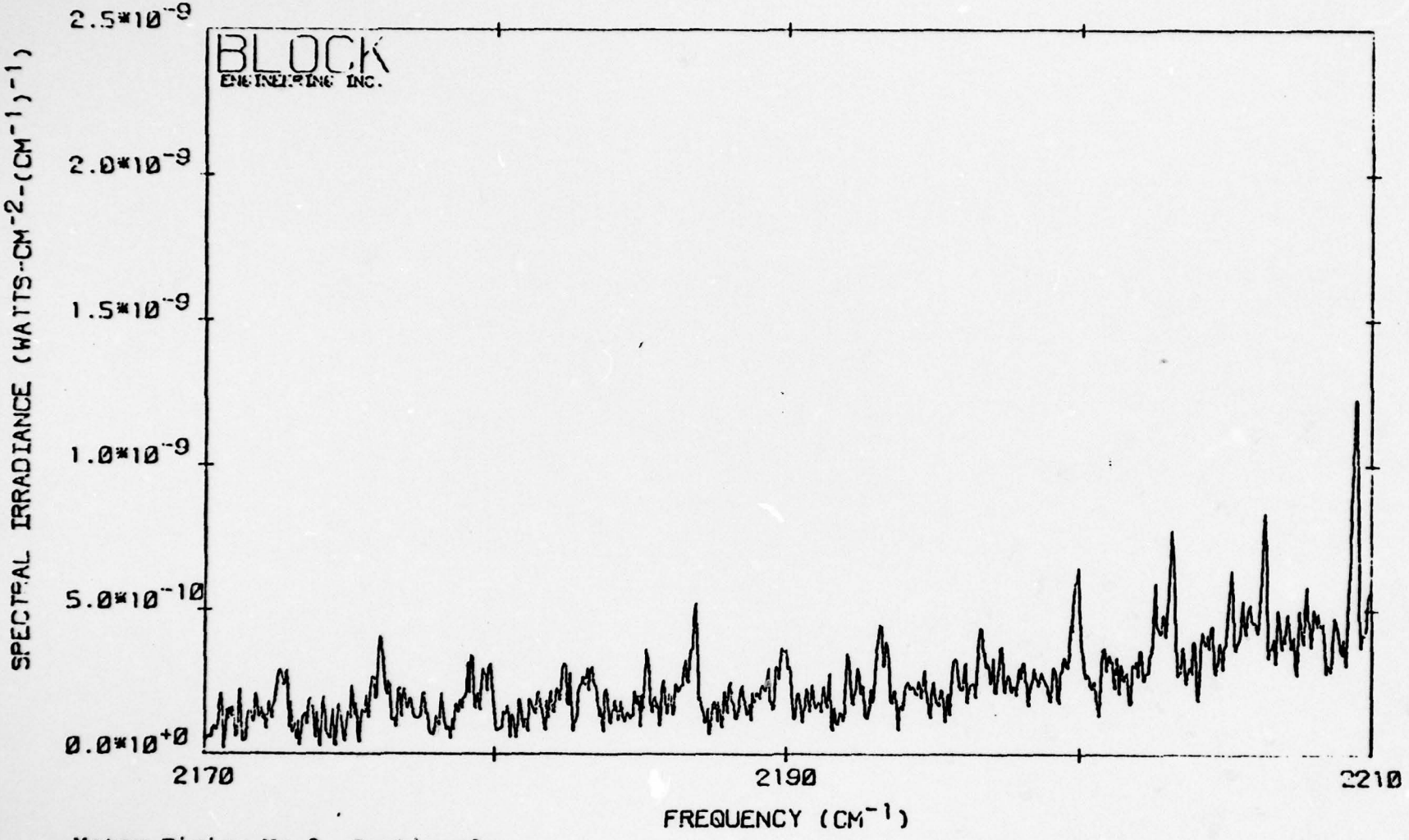

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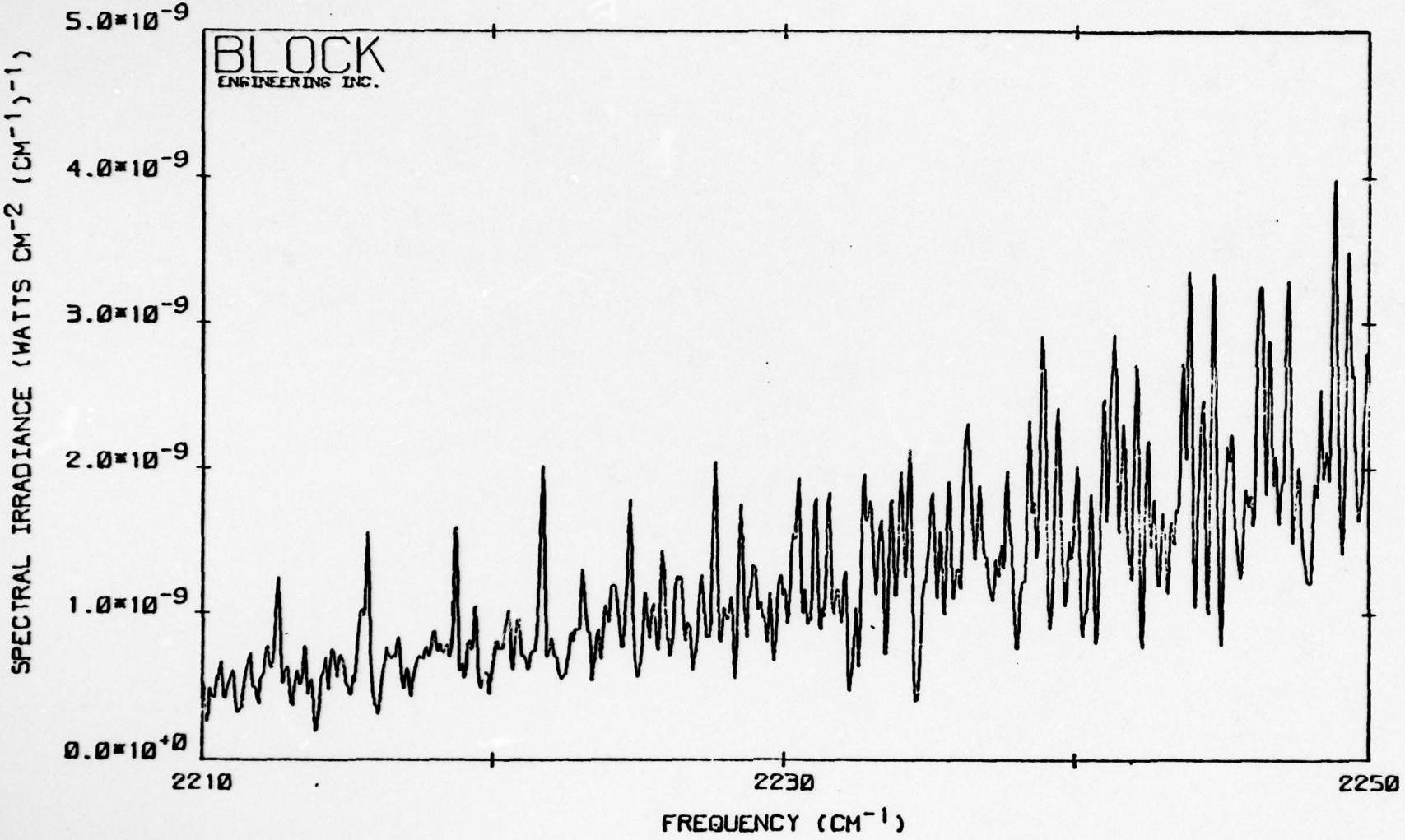

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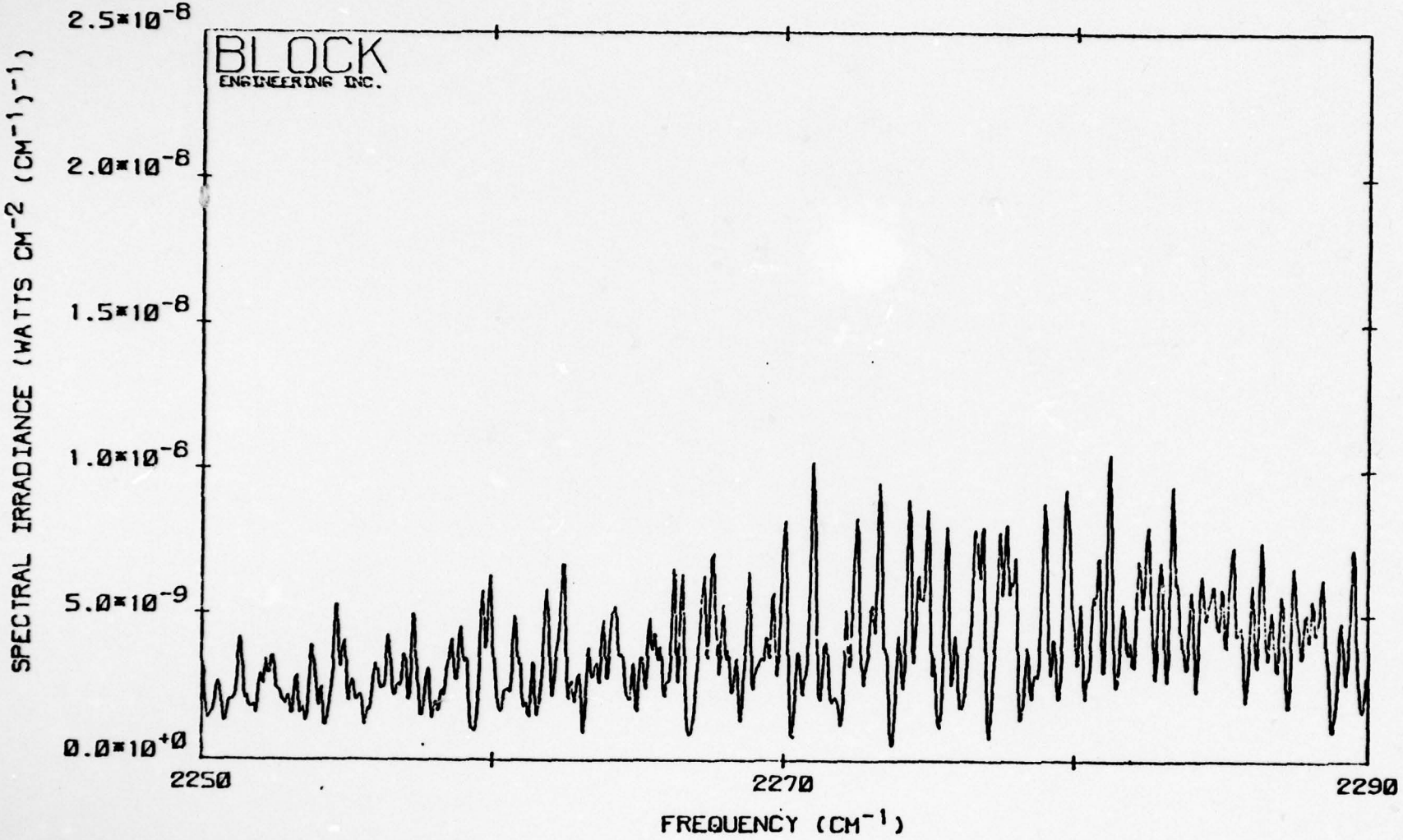

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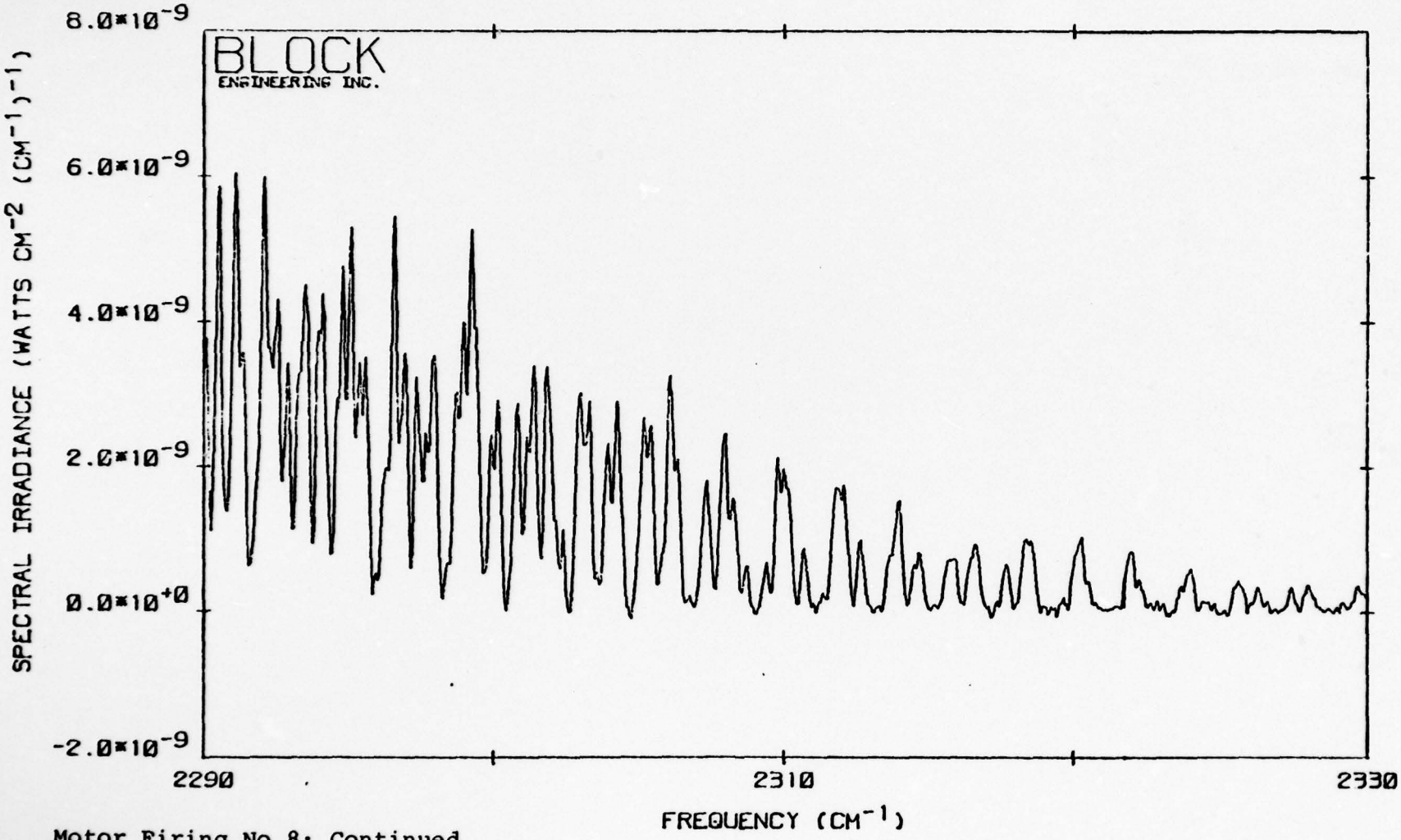

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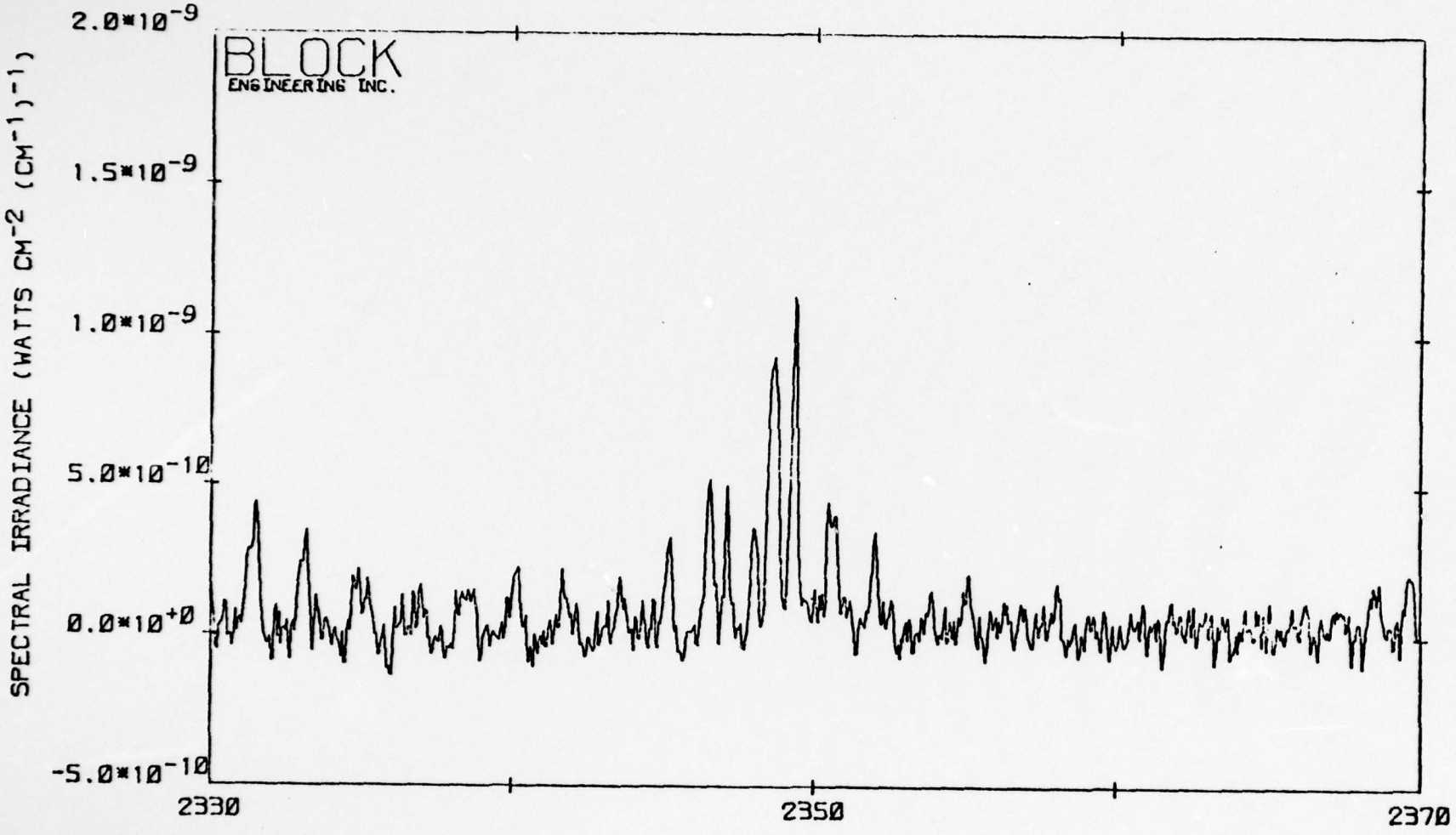

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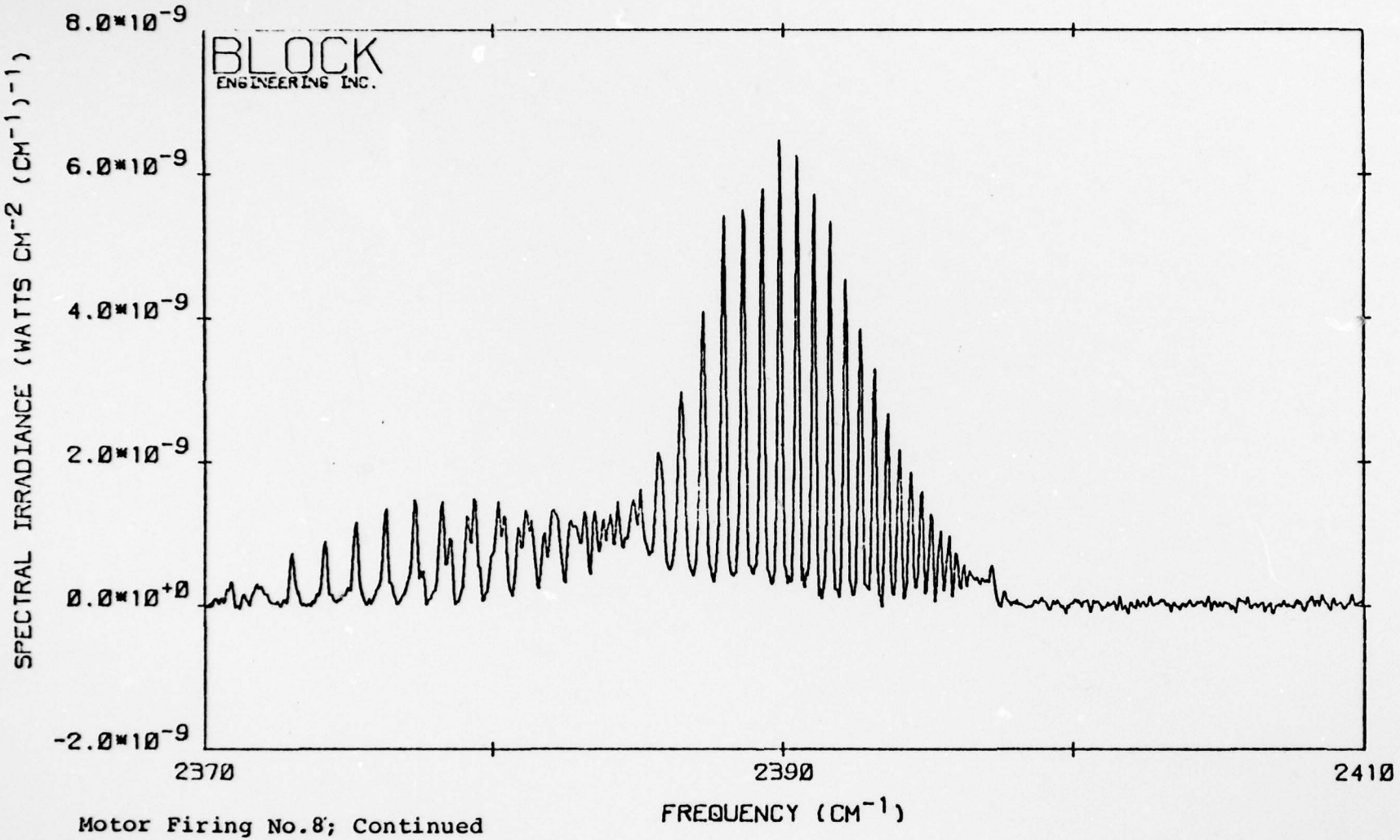
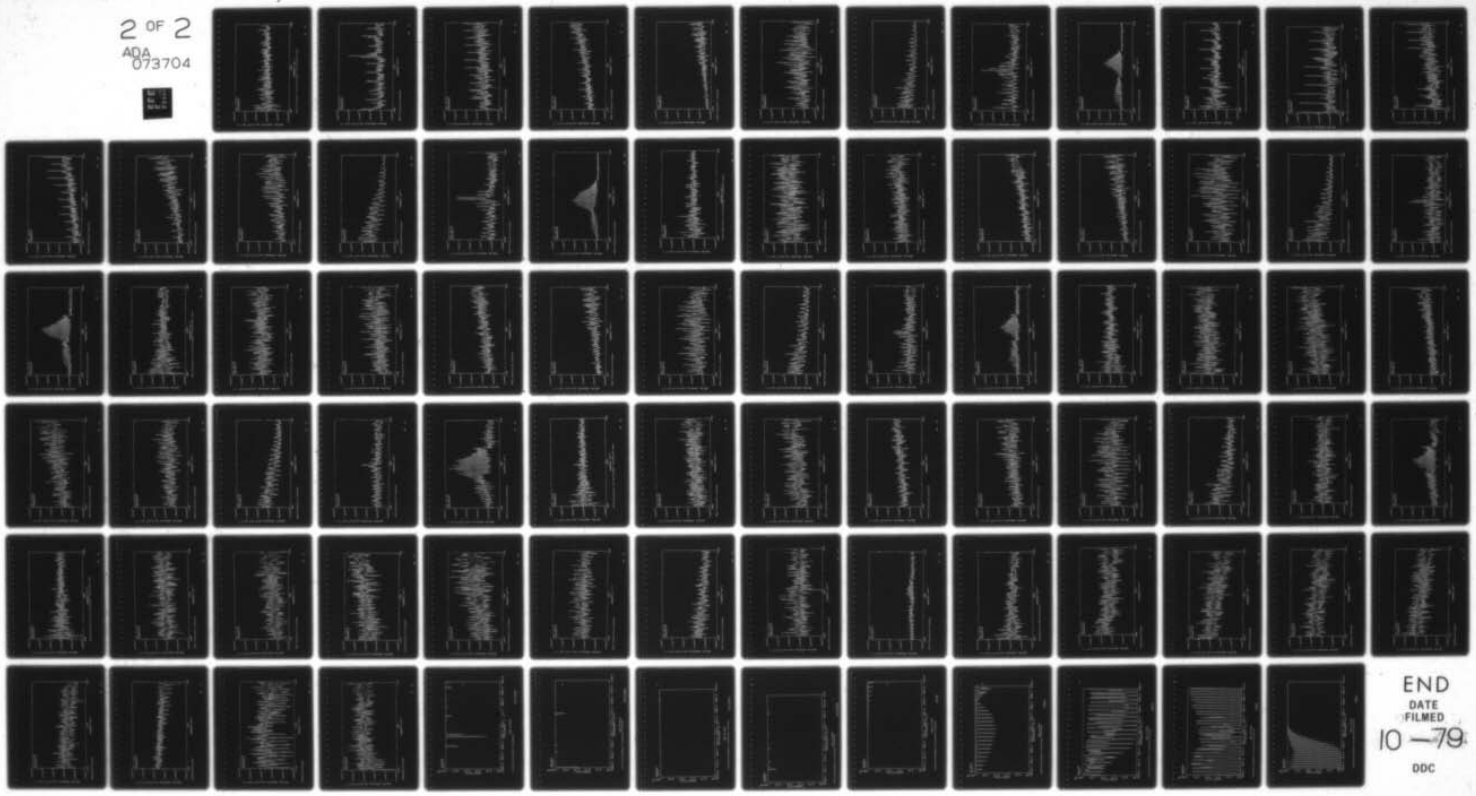


Motor Firing No.8; Continued

AD-A073 704 BLOCK ENGINEERING INC CAMBRIDGE MASS F/G 17/5
0.1 WAVENUMBER SPECTRAL MEASUREMENTS IN THE REGION FROM 2050 TO--ETC(U)
DEC 78 M J PERSKY N60530-78-C-0272
UNCLASSIFIED BEI-78-761 NL

2 OF 2
ADA 073704



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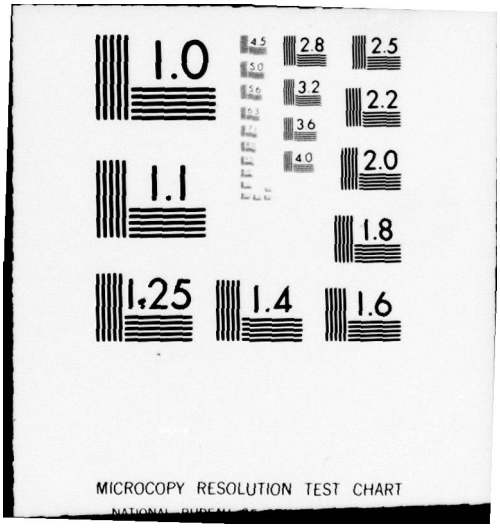
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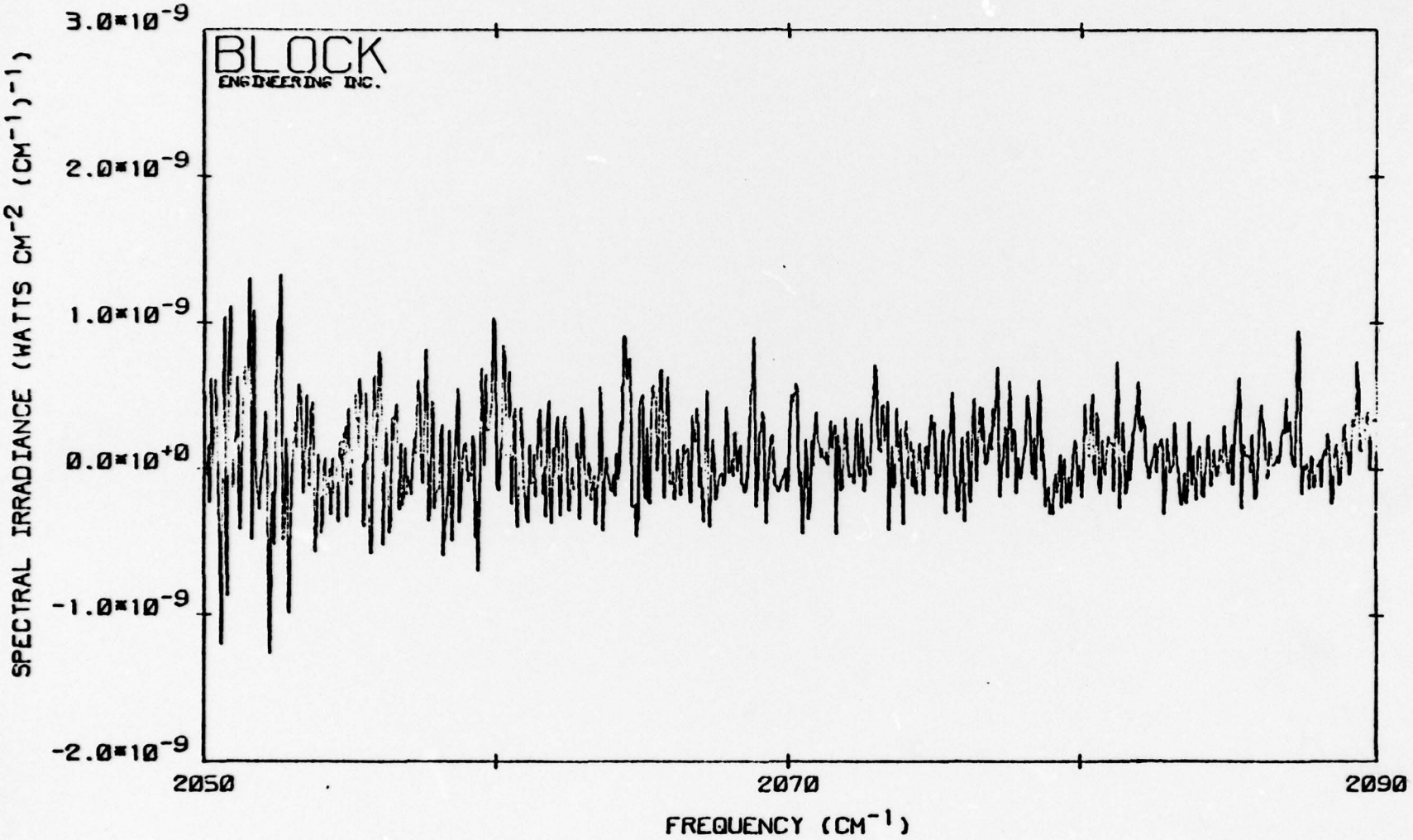
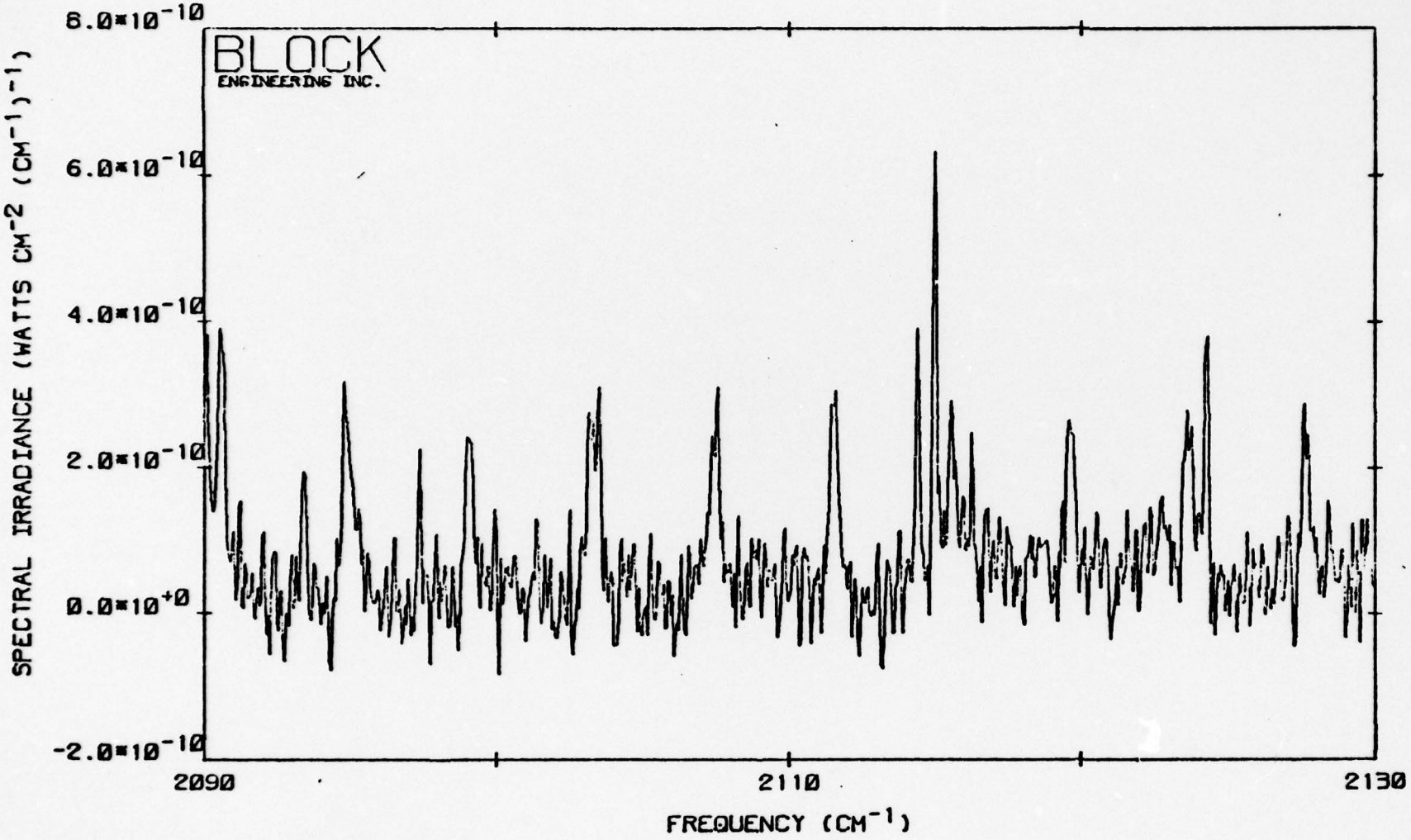
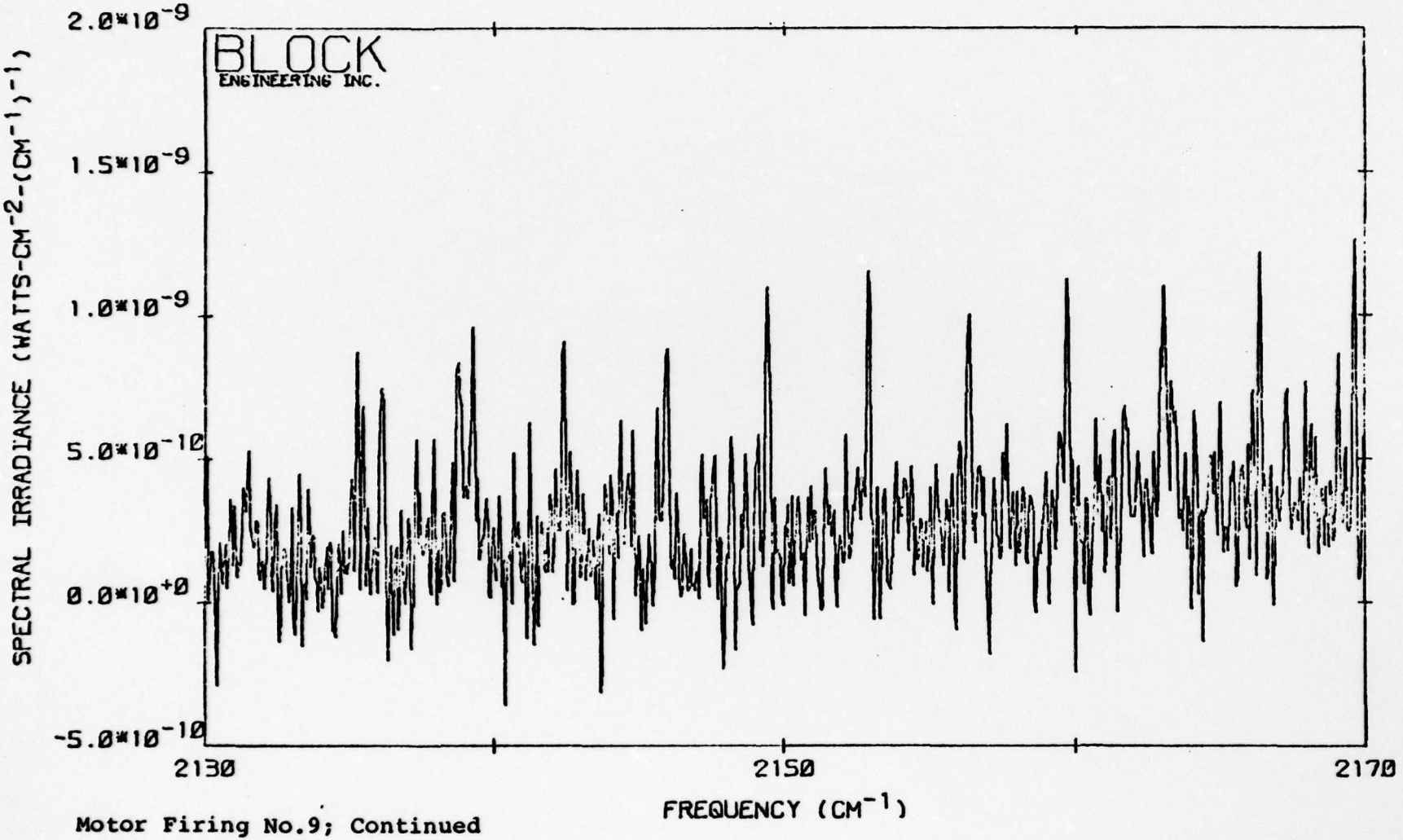
MICROCOPY RESOLUTION TEST CHART



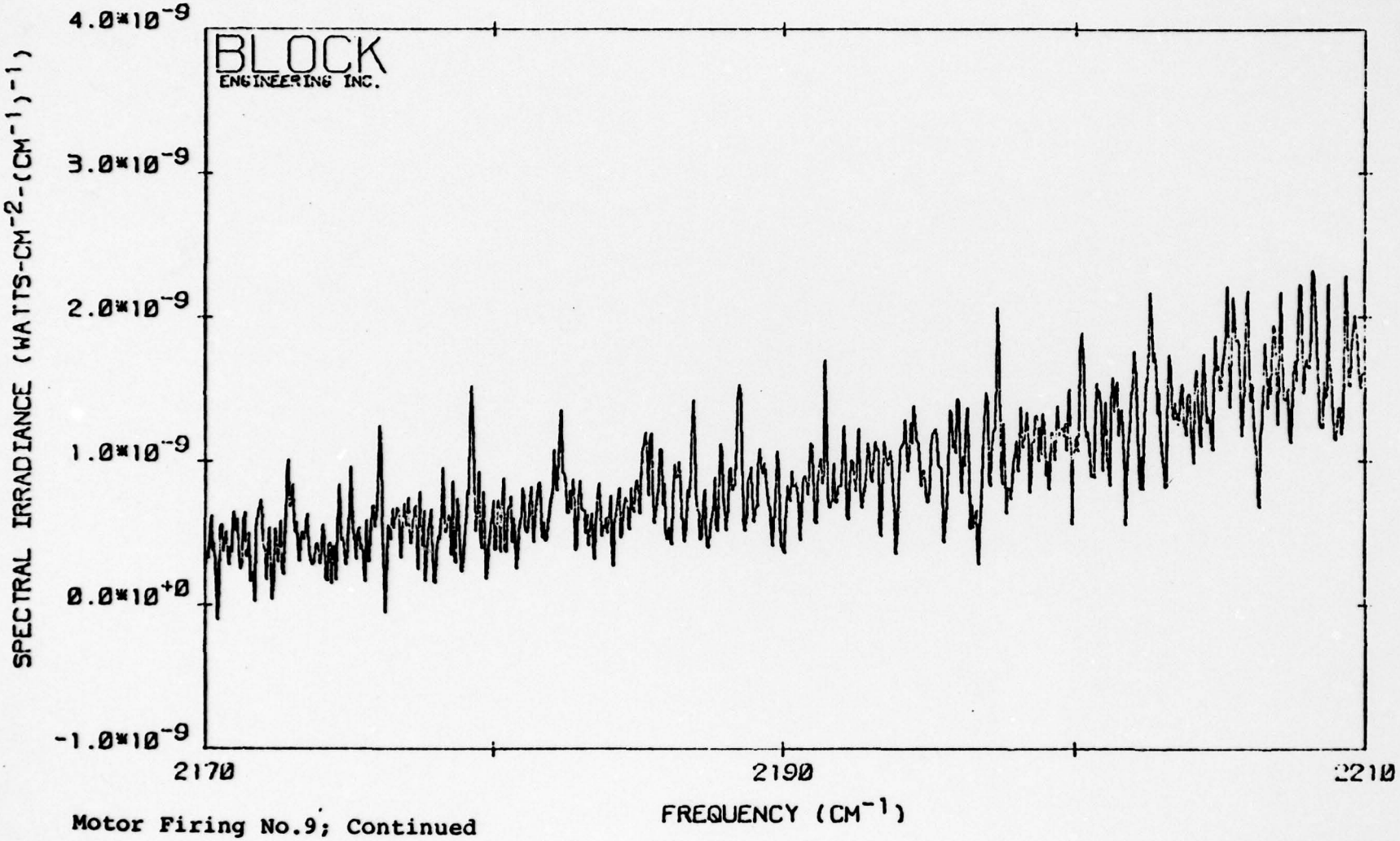
Motor Firing No.9; 12.19 km Altitude; 25 cm From Exit Plane



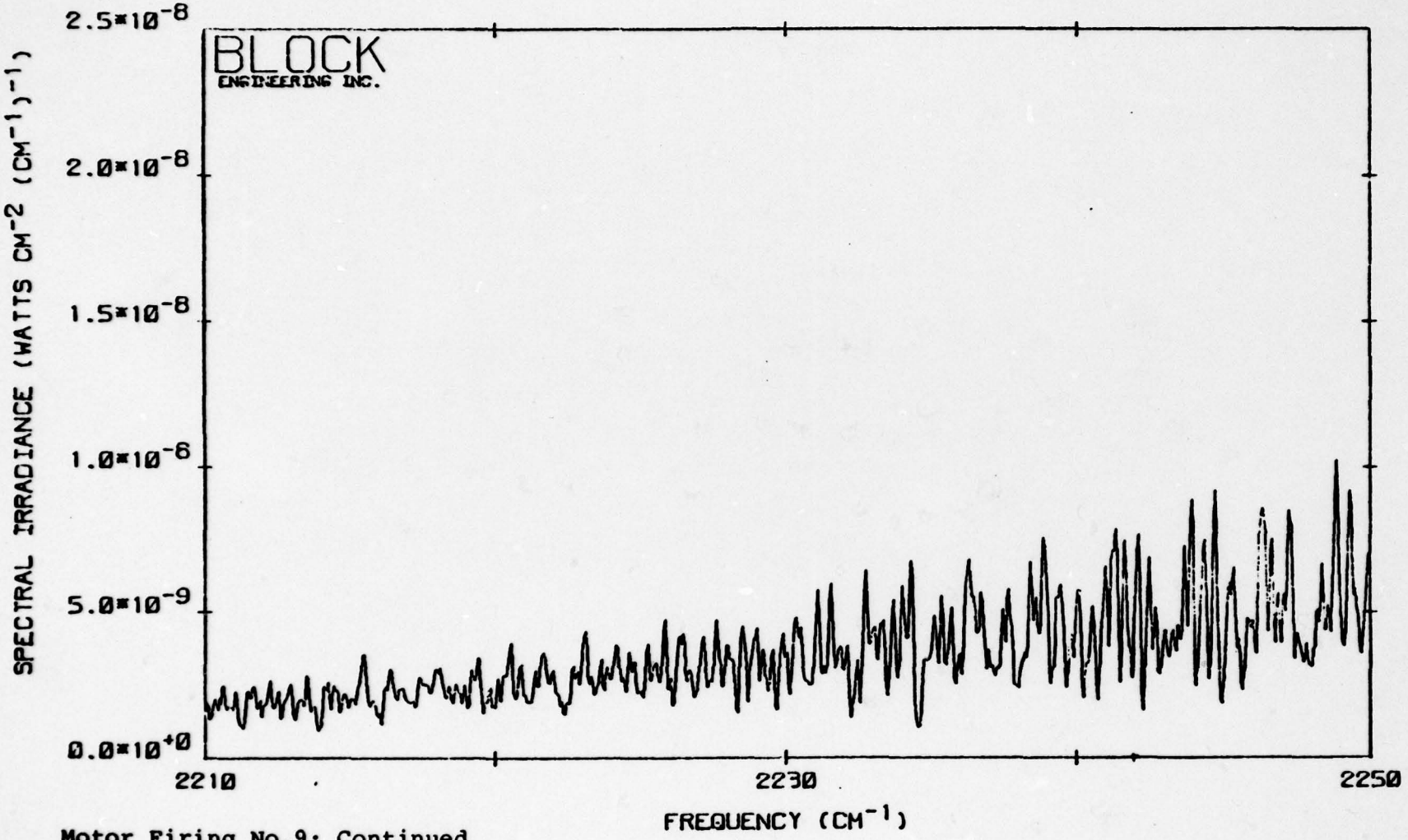
Motor Firing No.9; Continued



Motor Firing No.9; Continued



Motor Firing No.9; Continued



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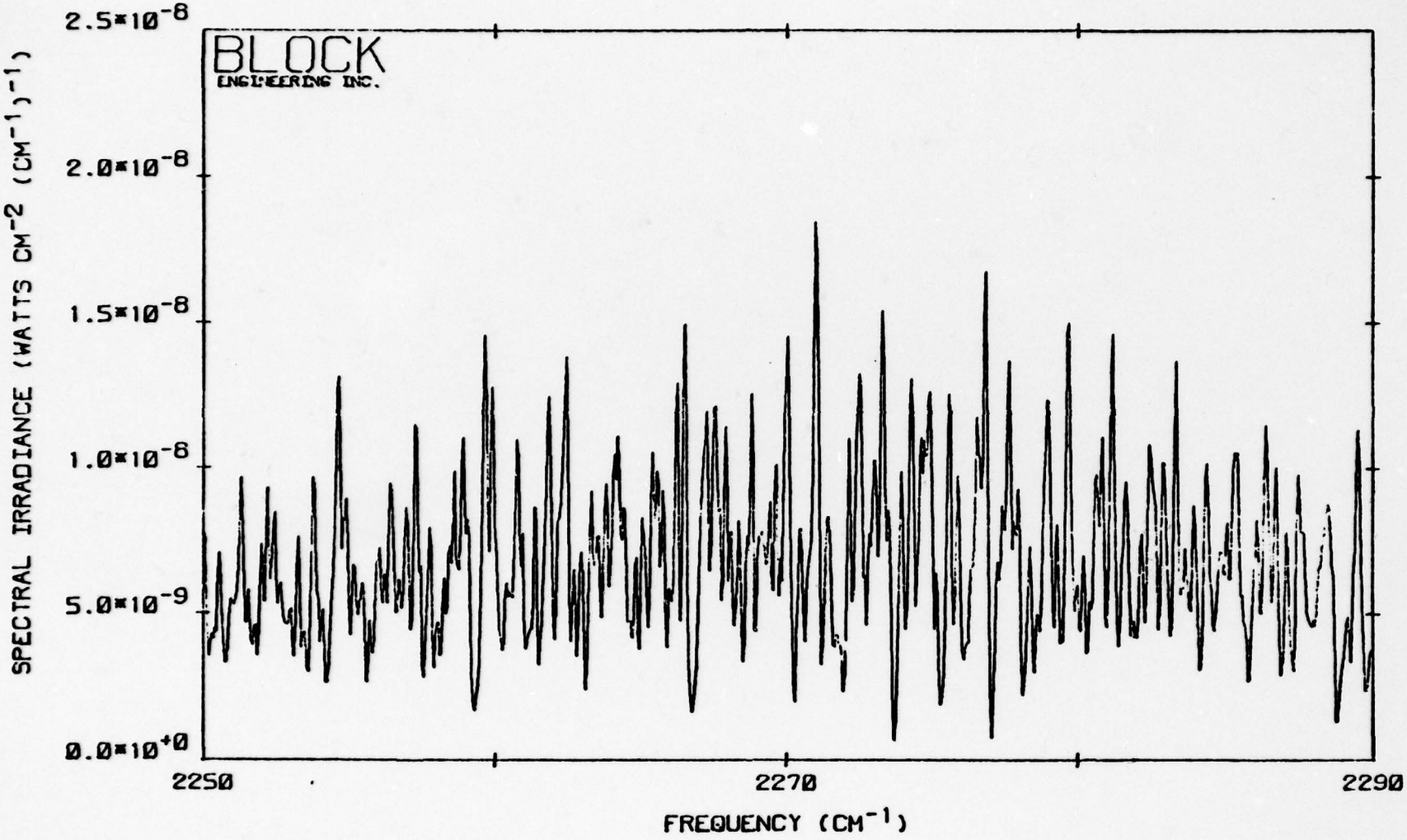

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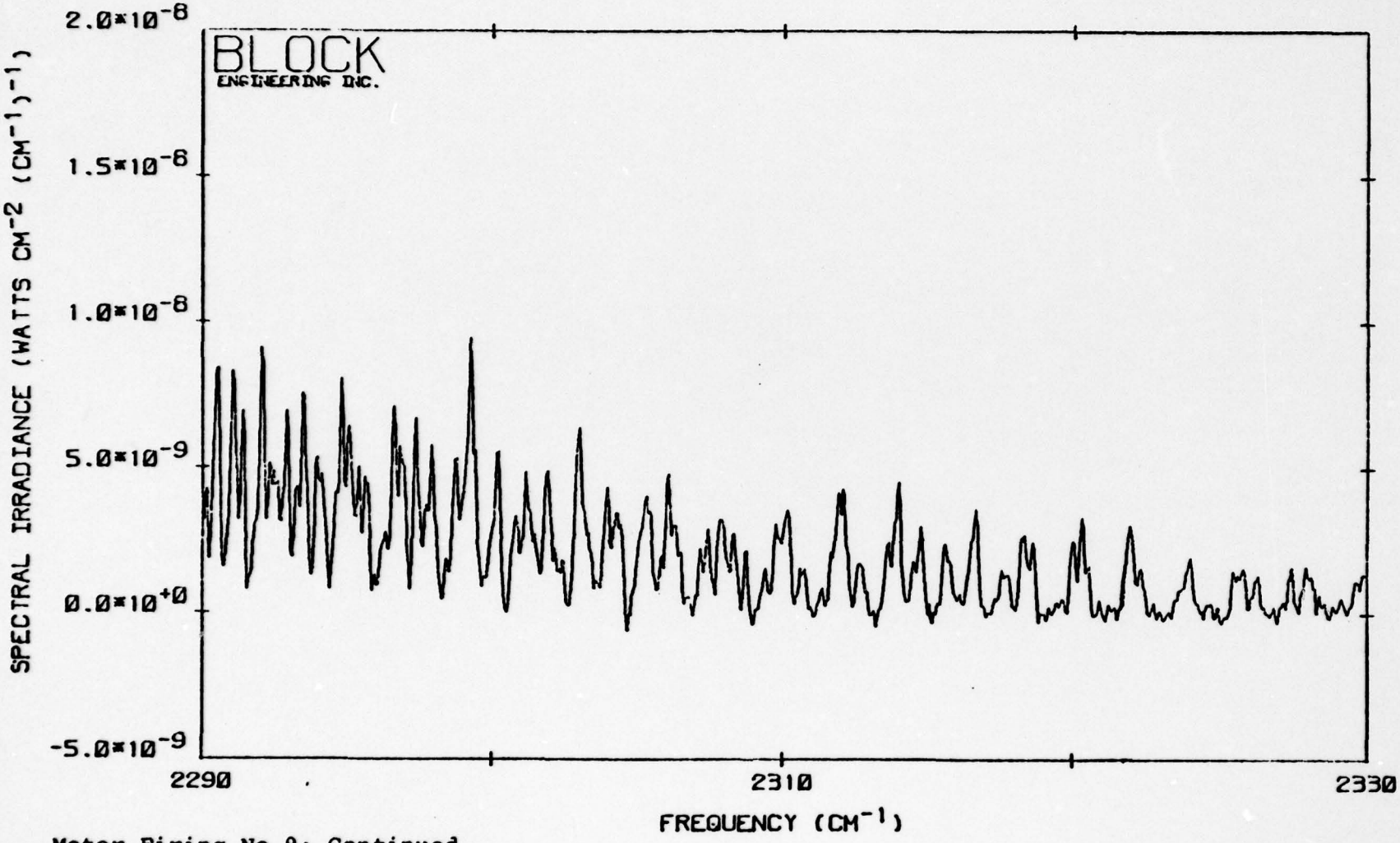

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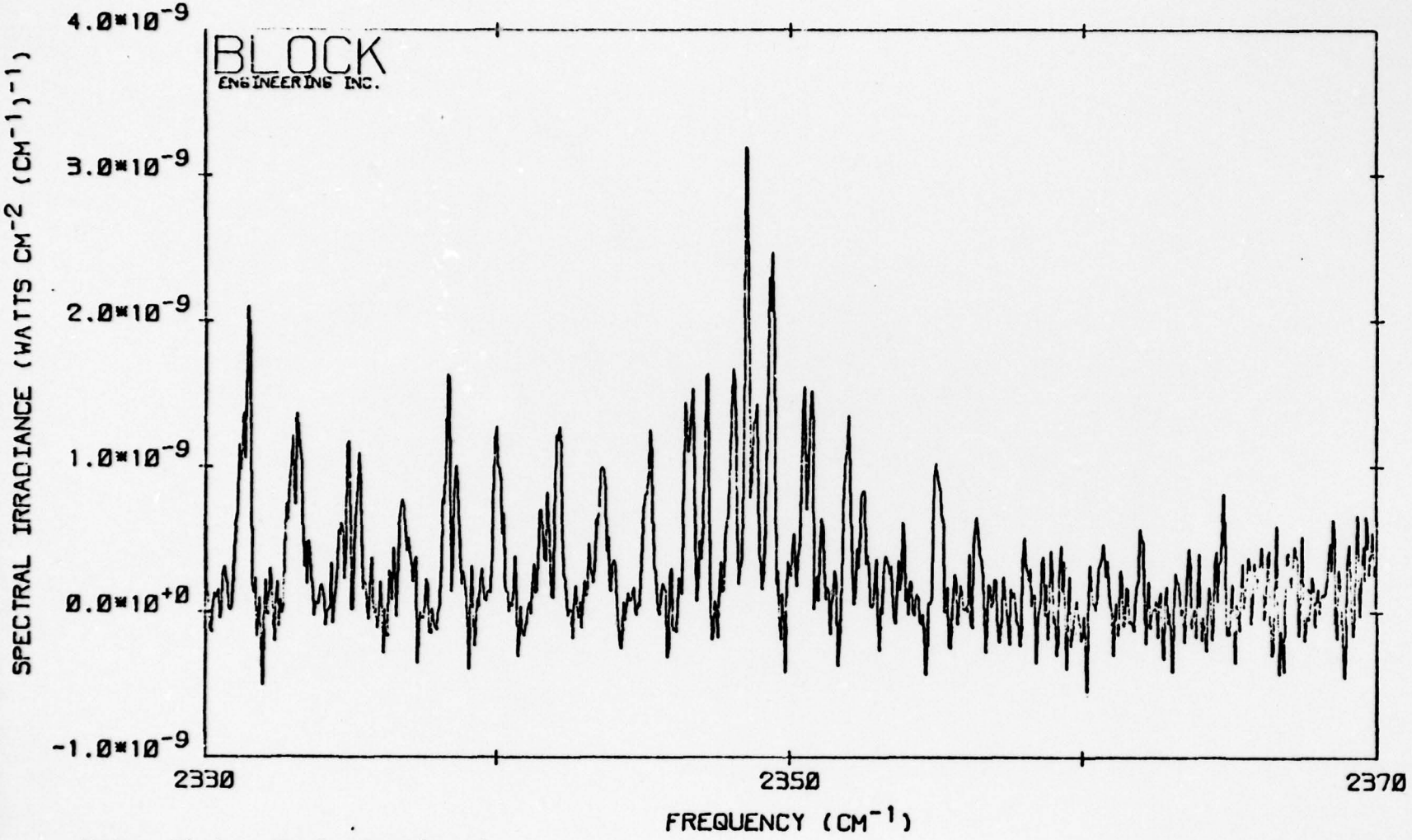

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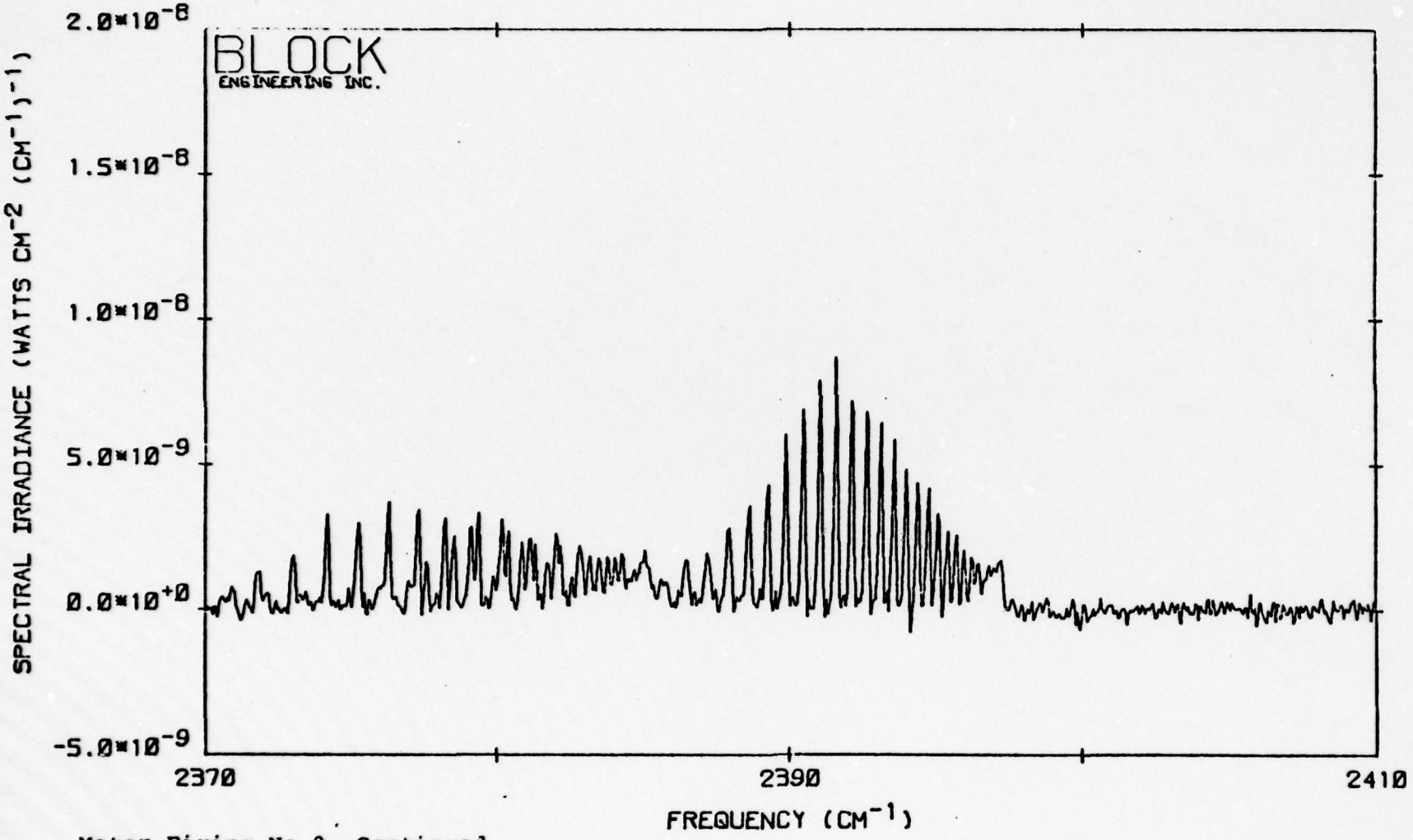

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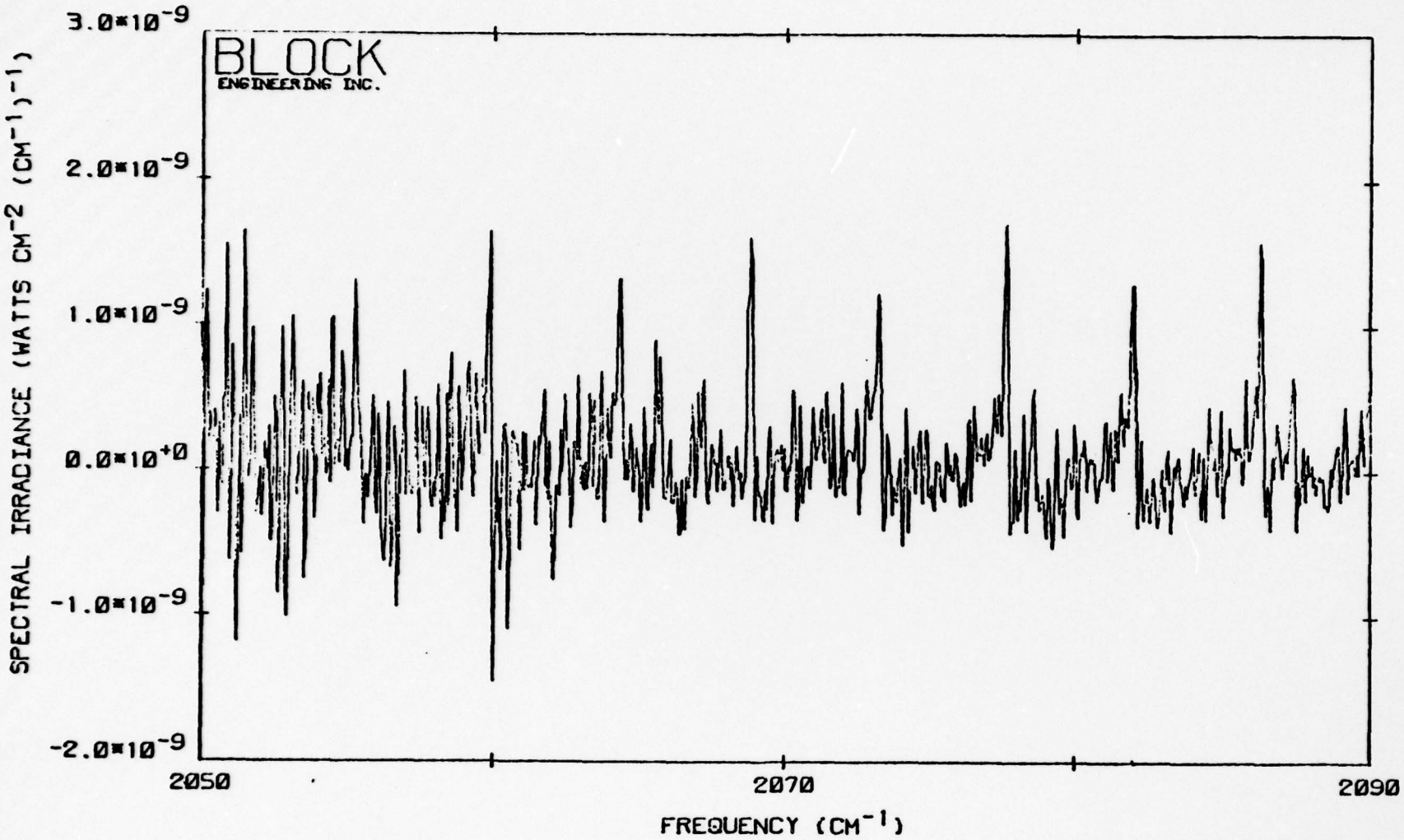
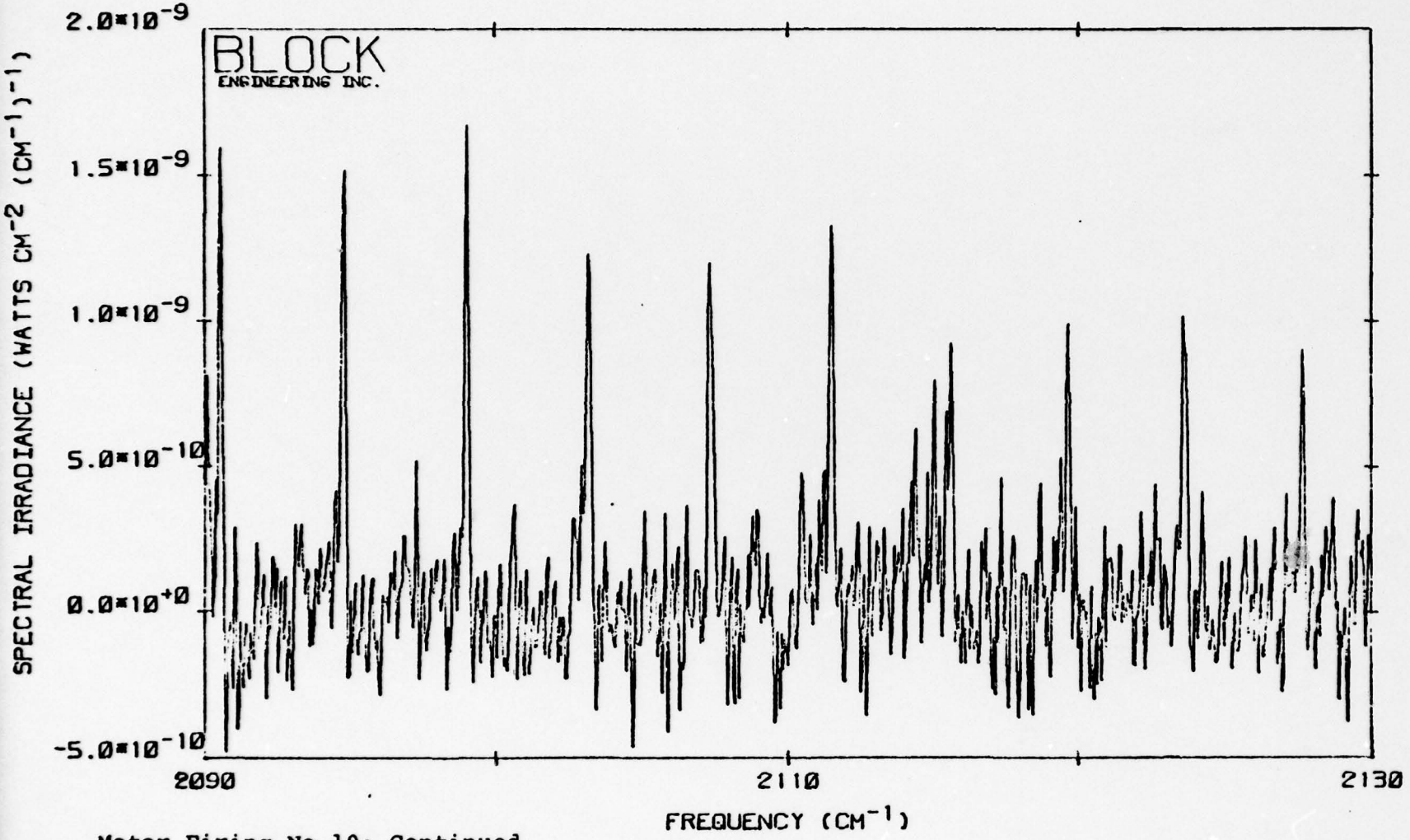
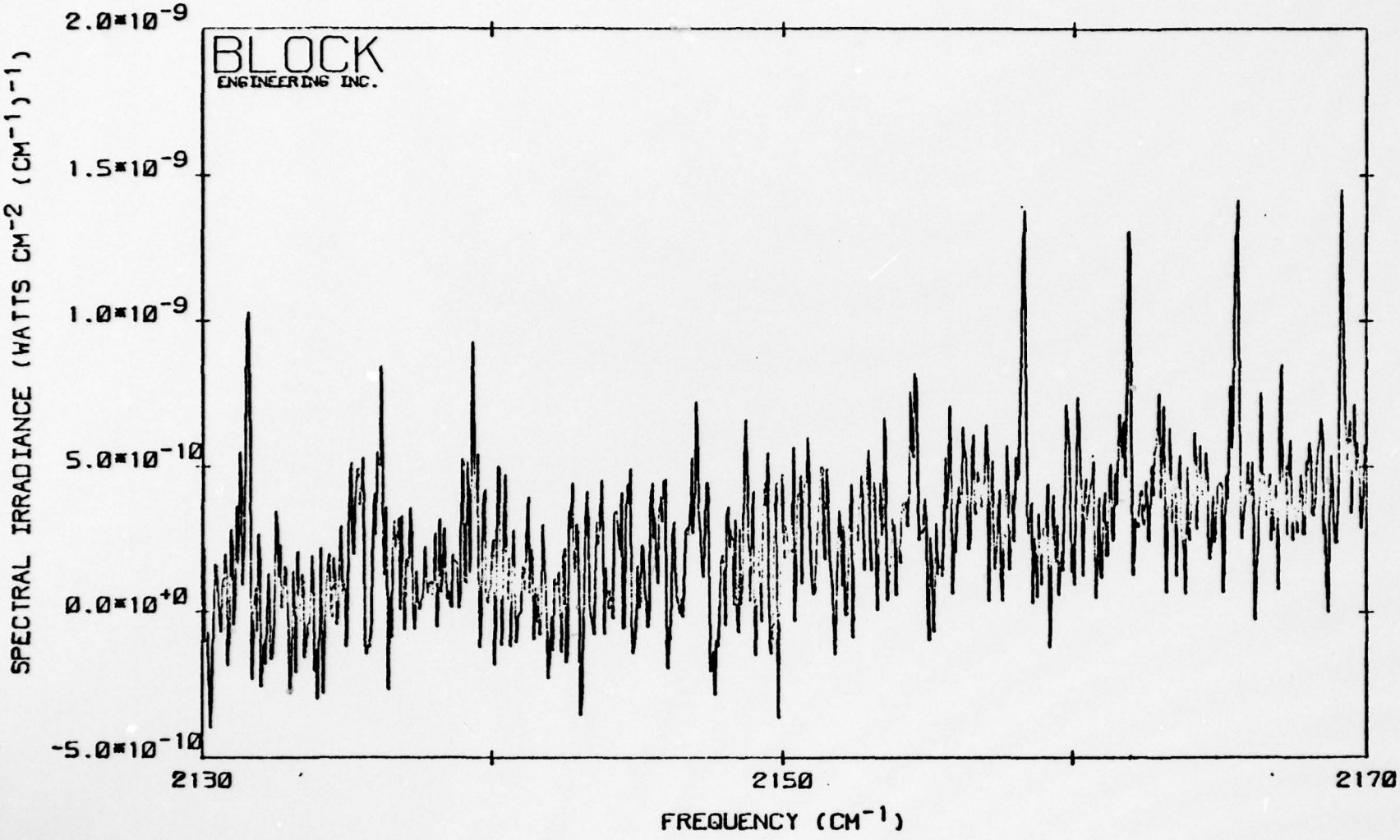


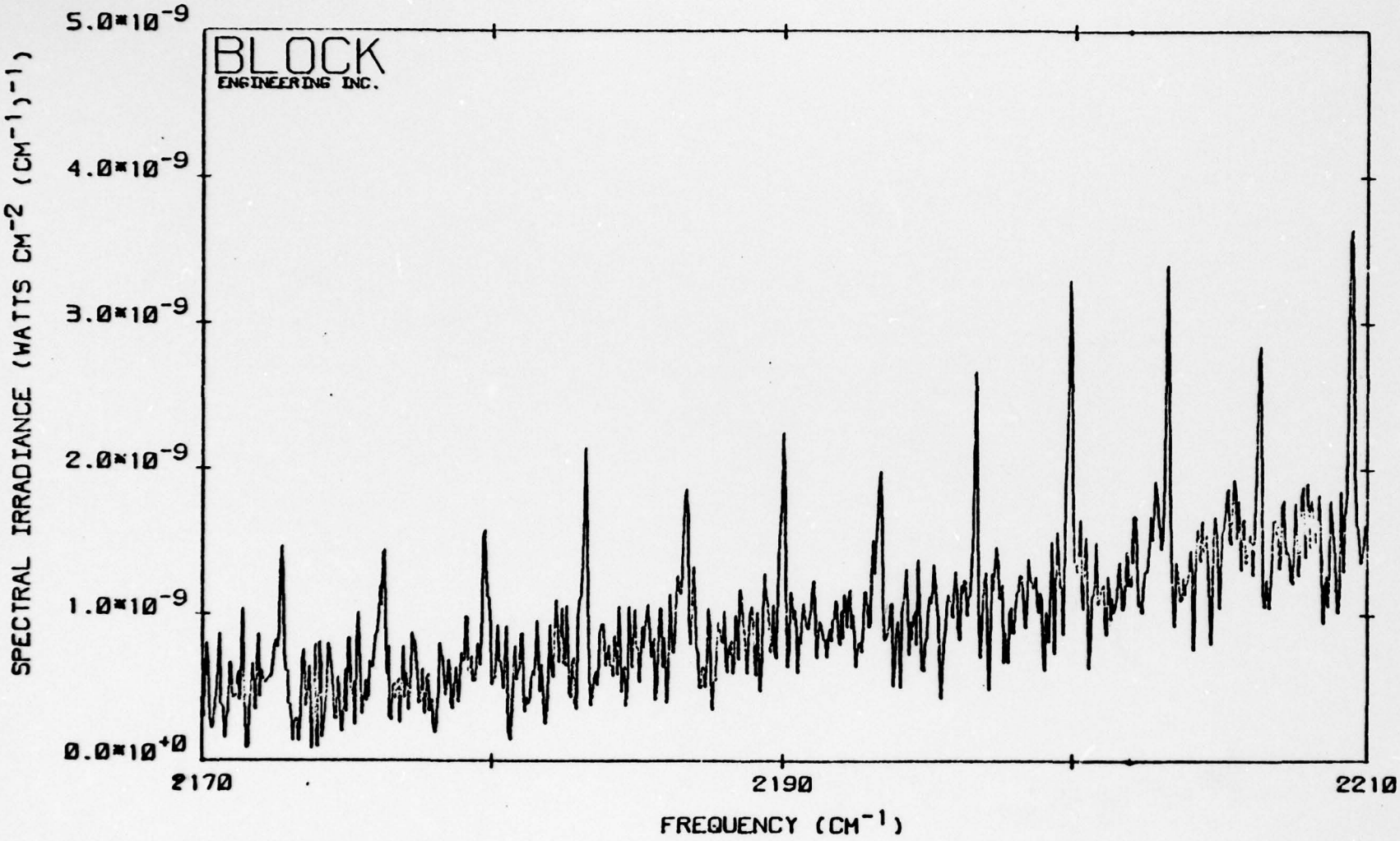
Motor Firing No.10; 0 km Altitude; 15 cm From Exit Plane



Motor Firing No.10; Continued



Motor Firing No.10; Continued



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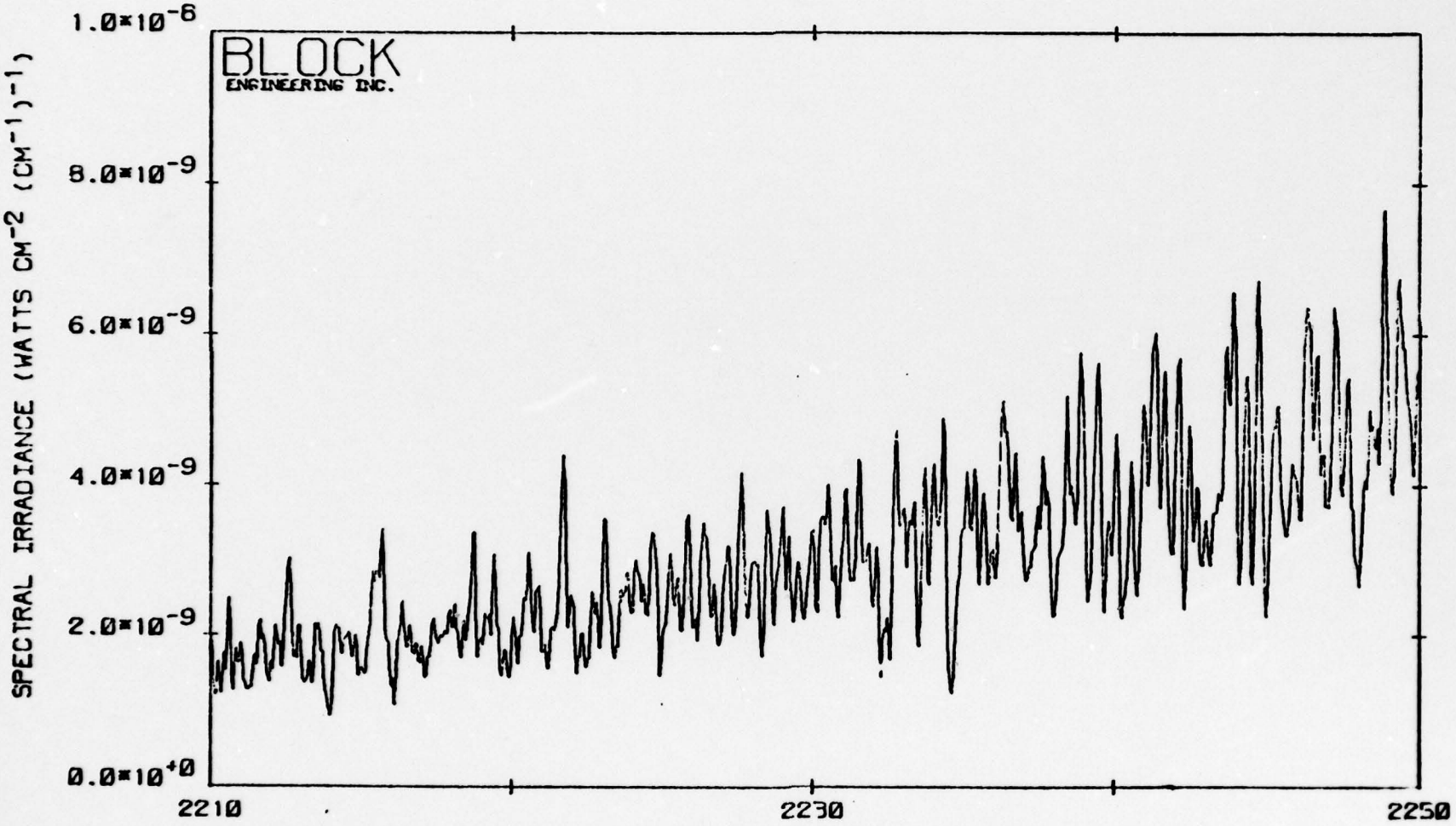
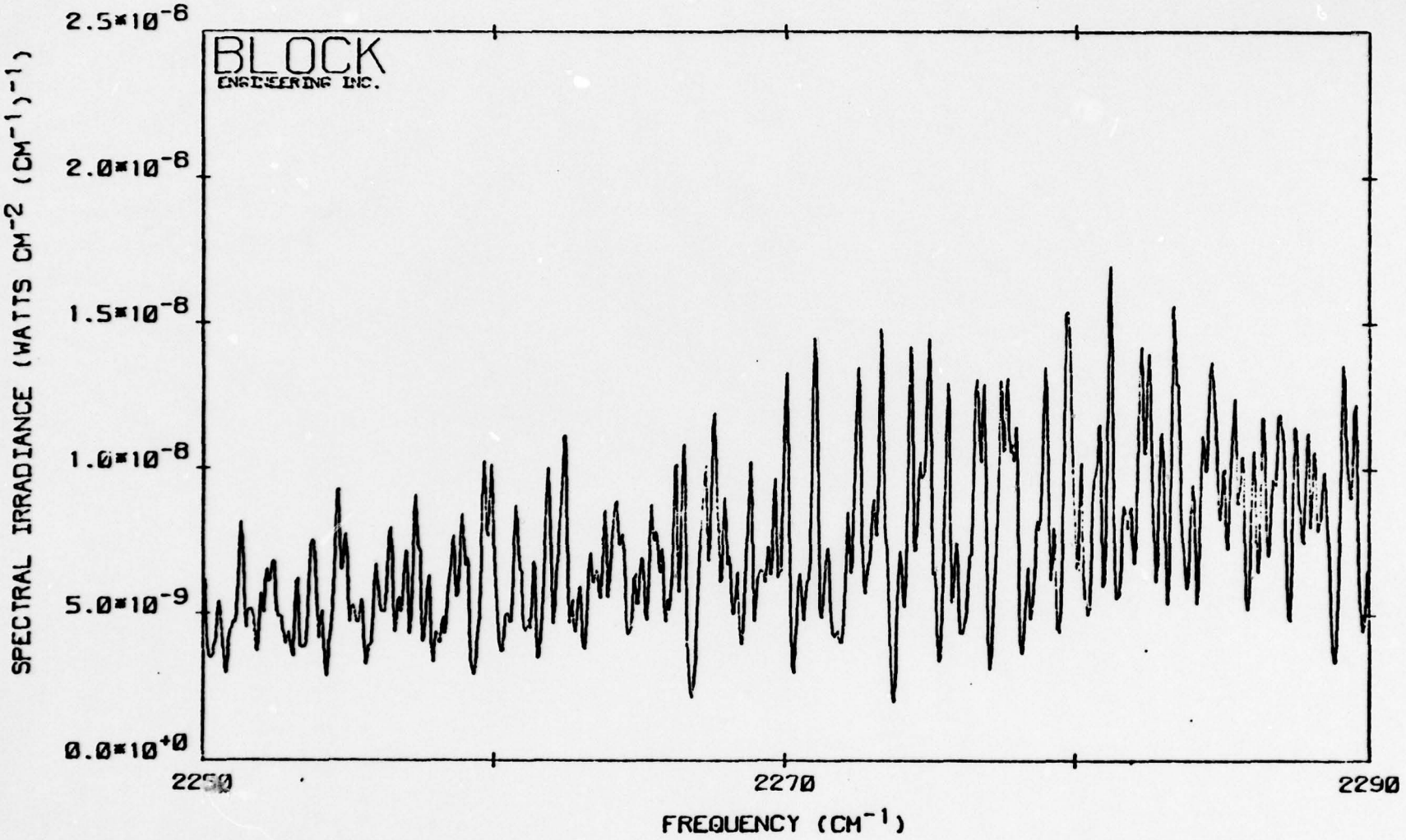
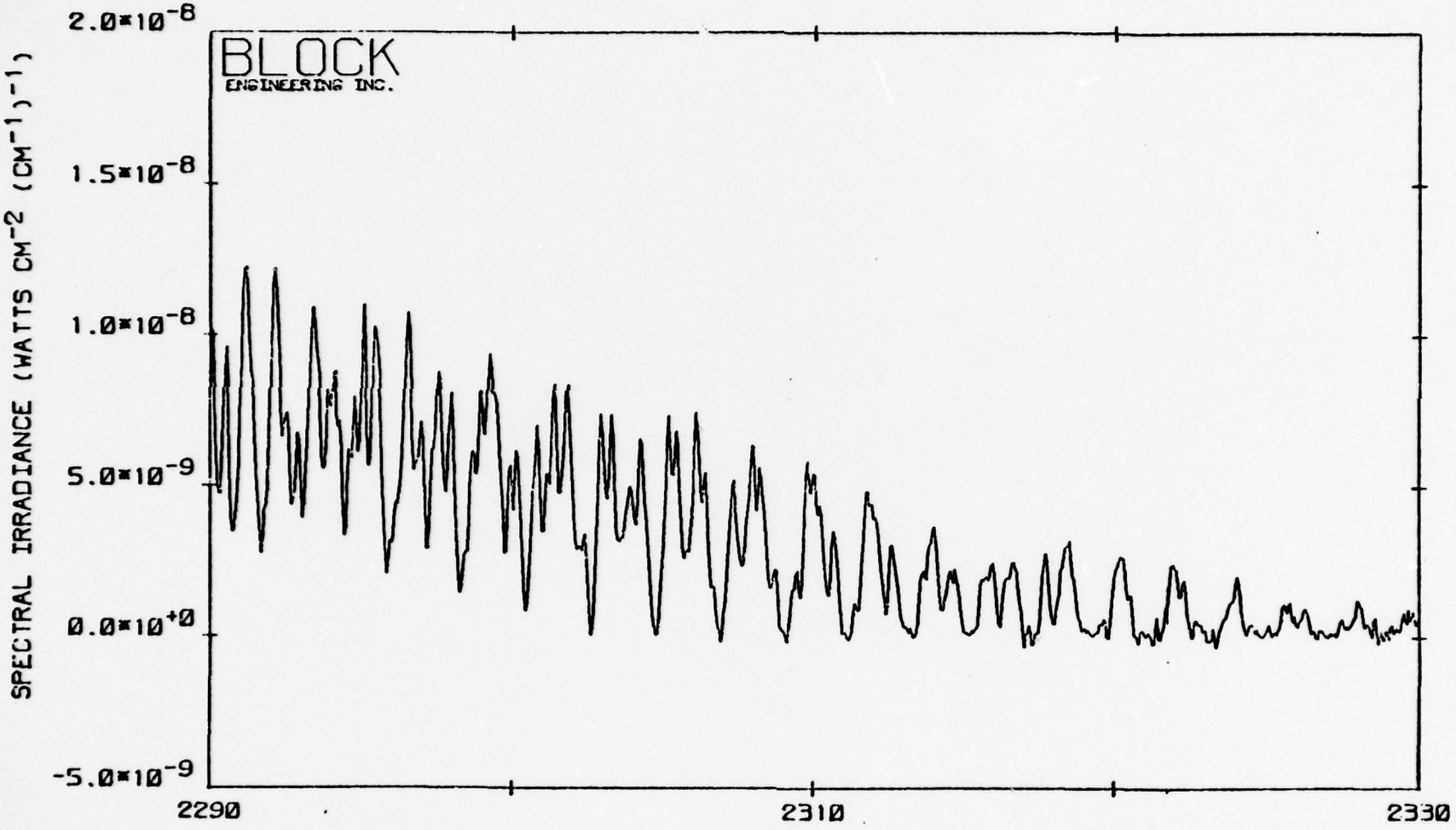


Motor Firing No.10; Continued



Motor Firing No.10; Continued



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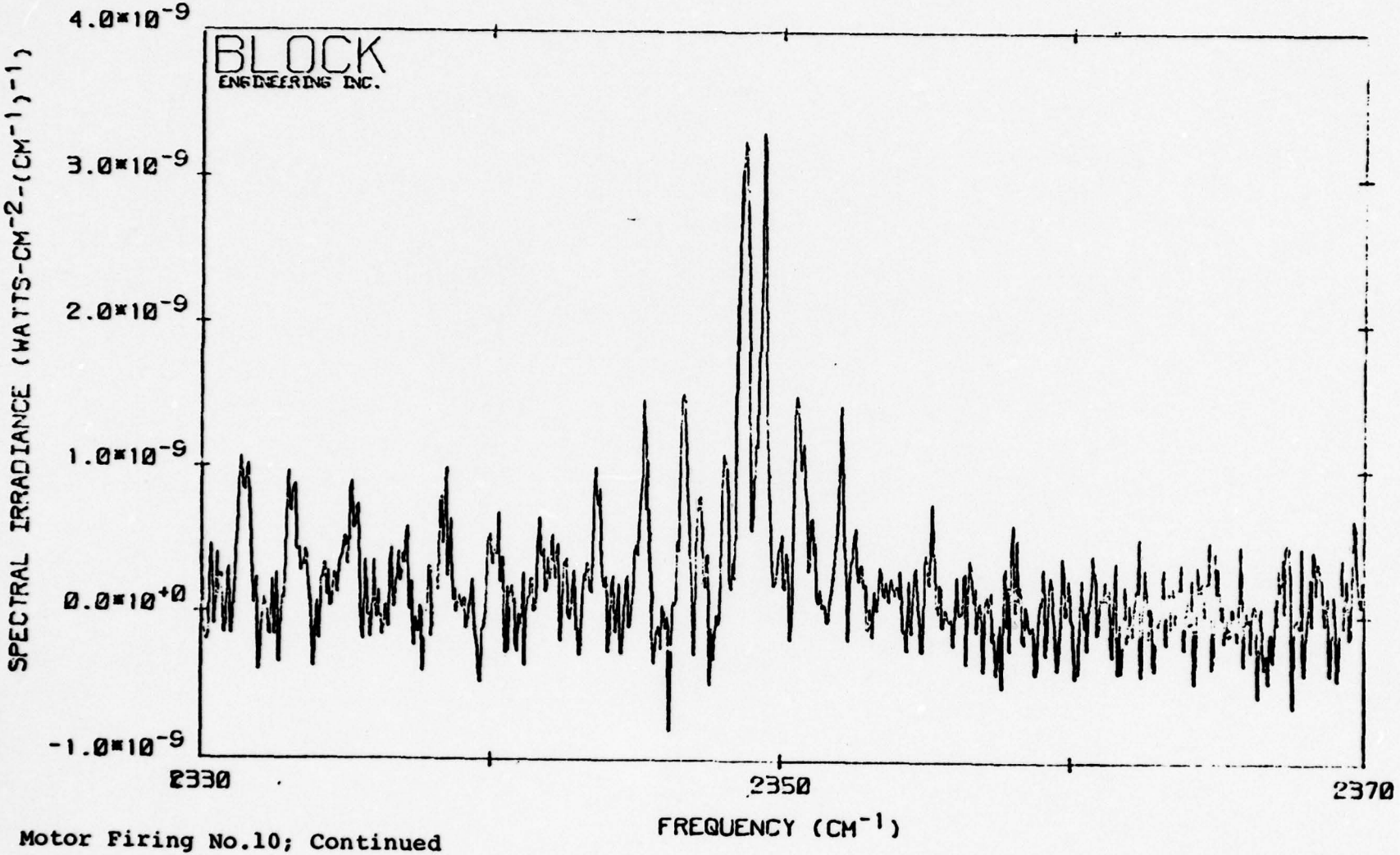
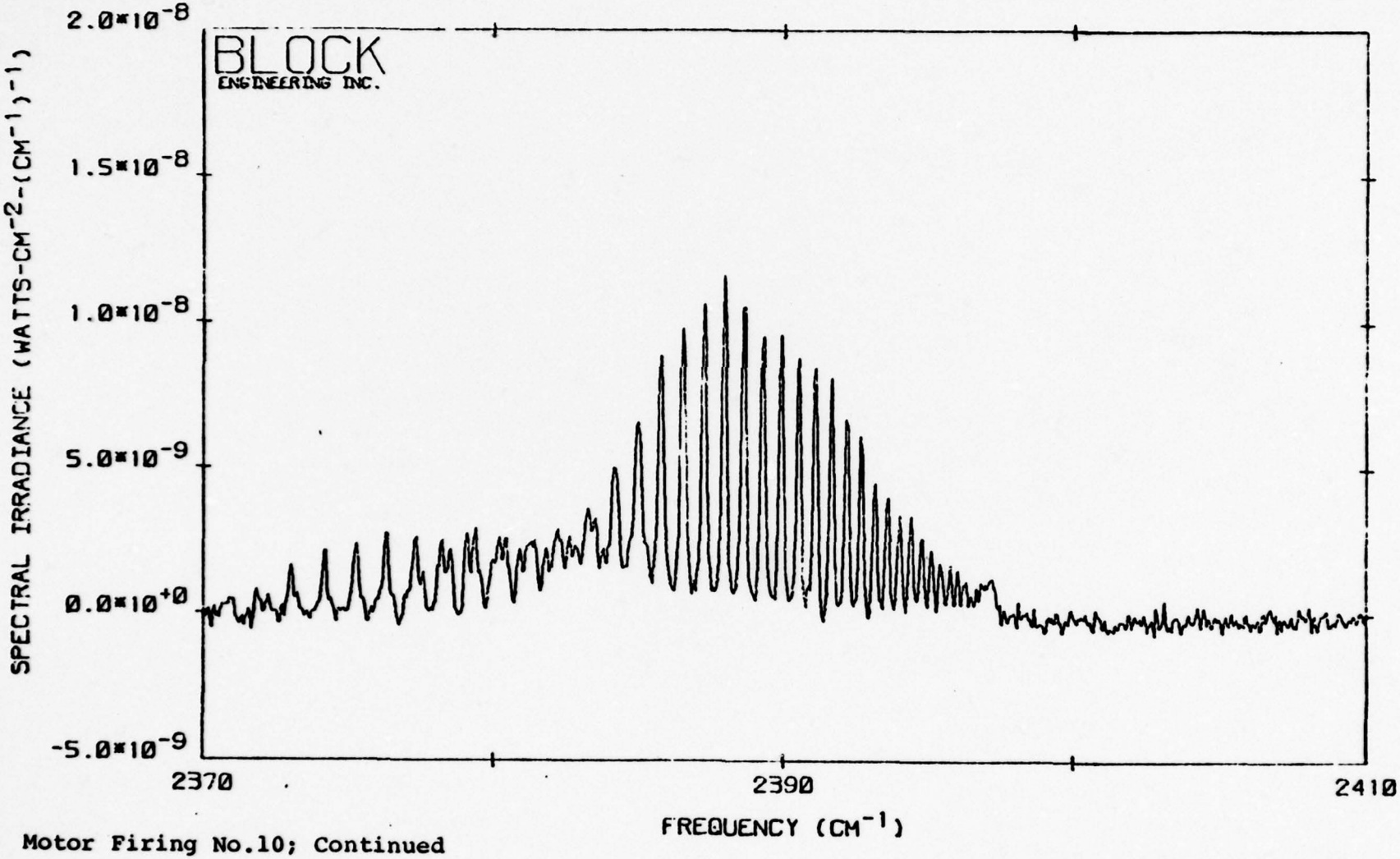
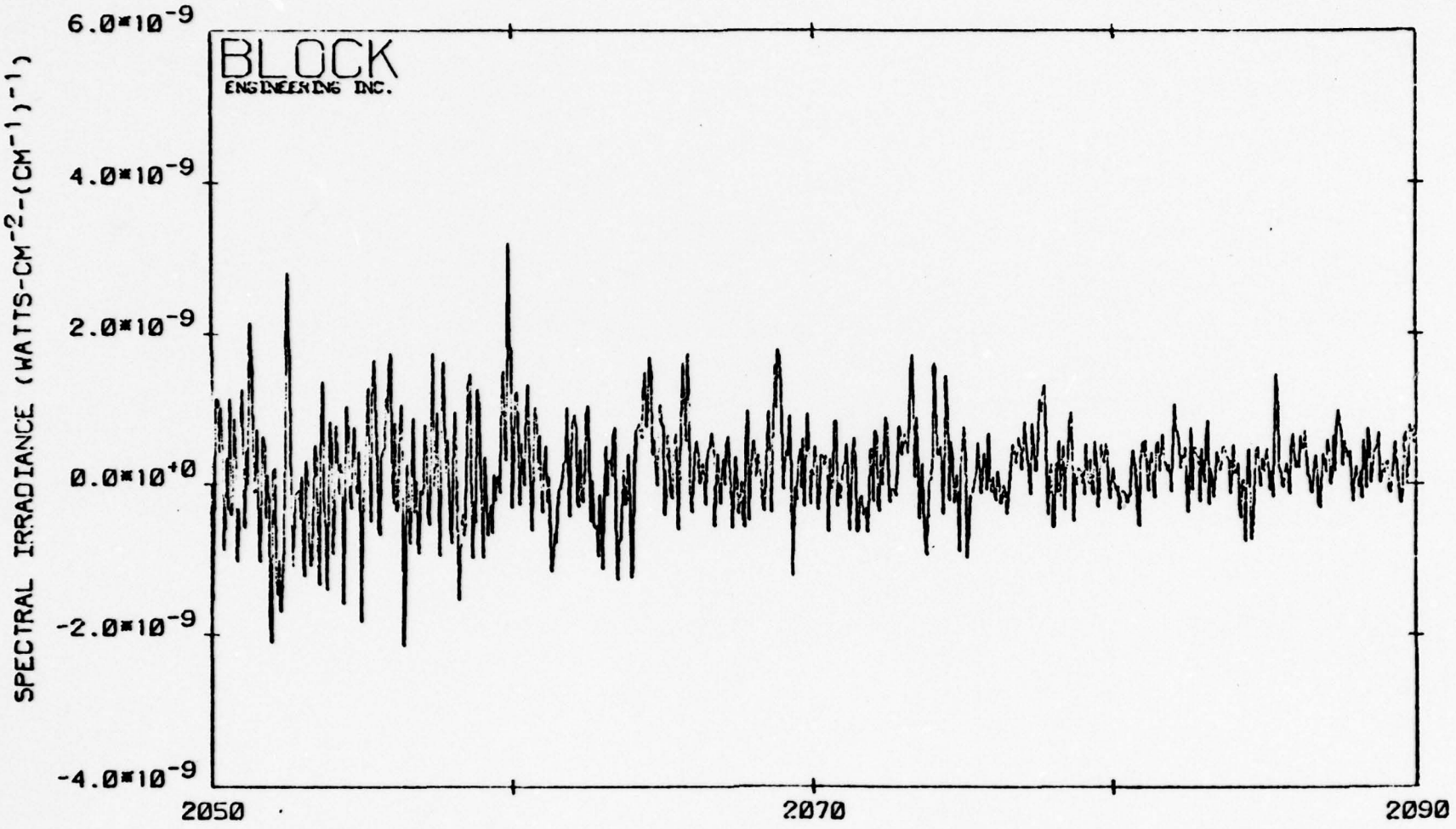


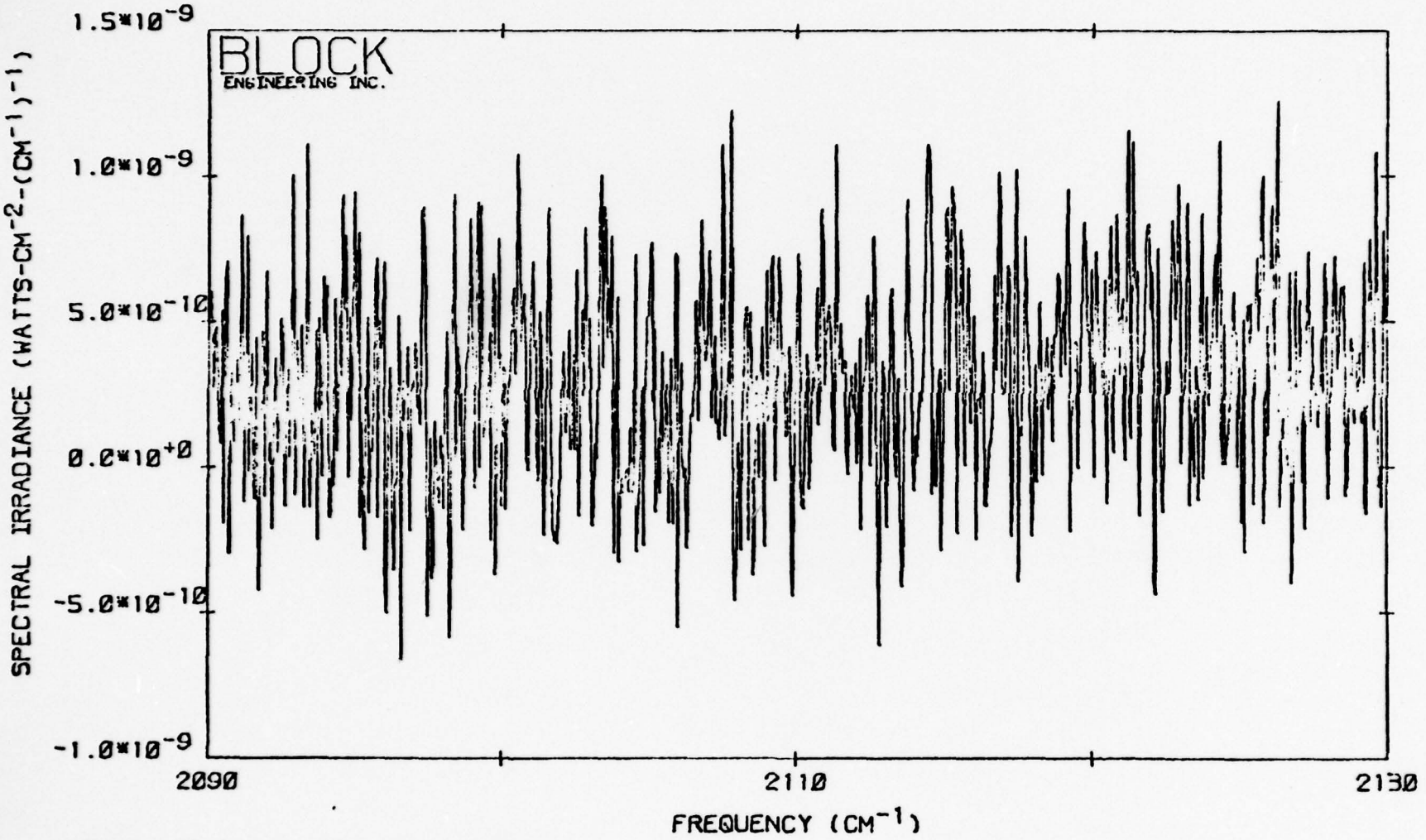
Motor Firing No.10; Continued



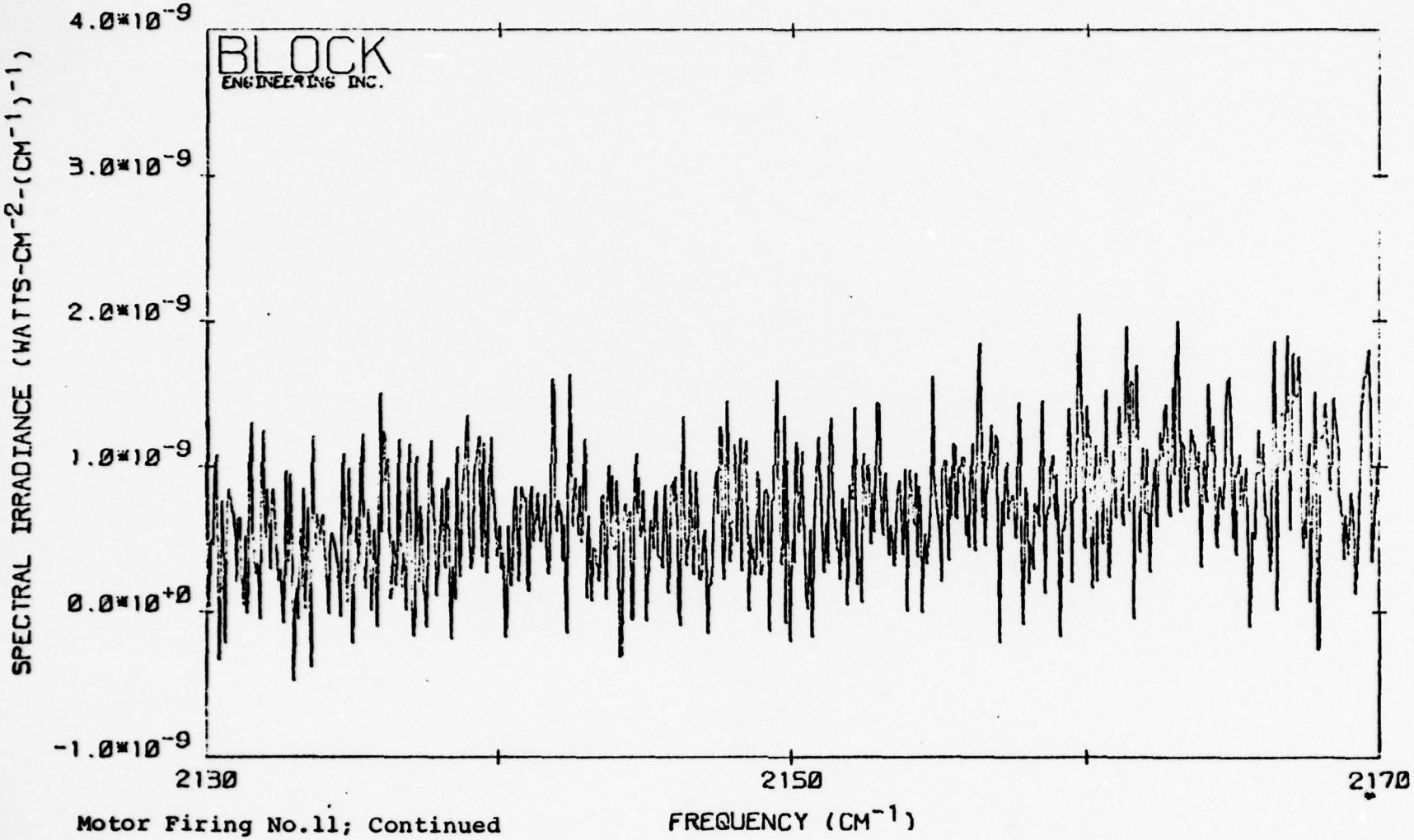
Motor Firing No.10; Continued



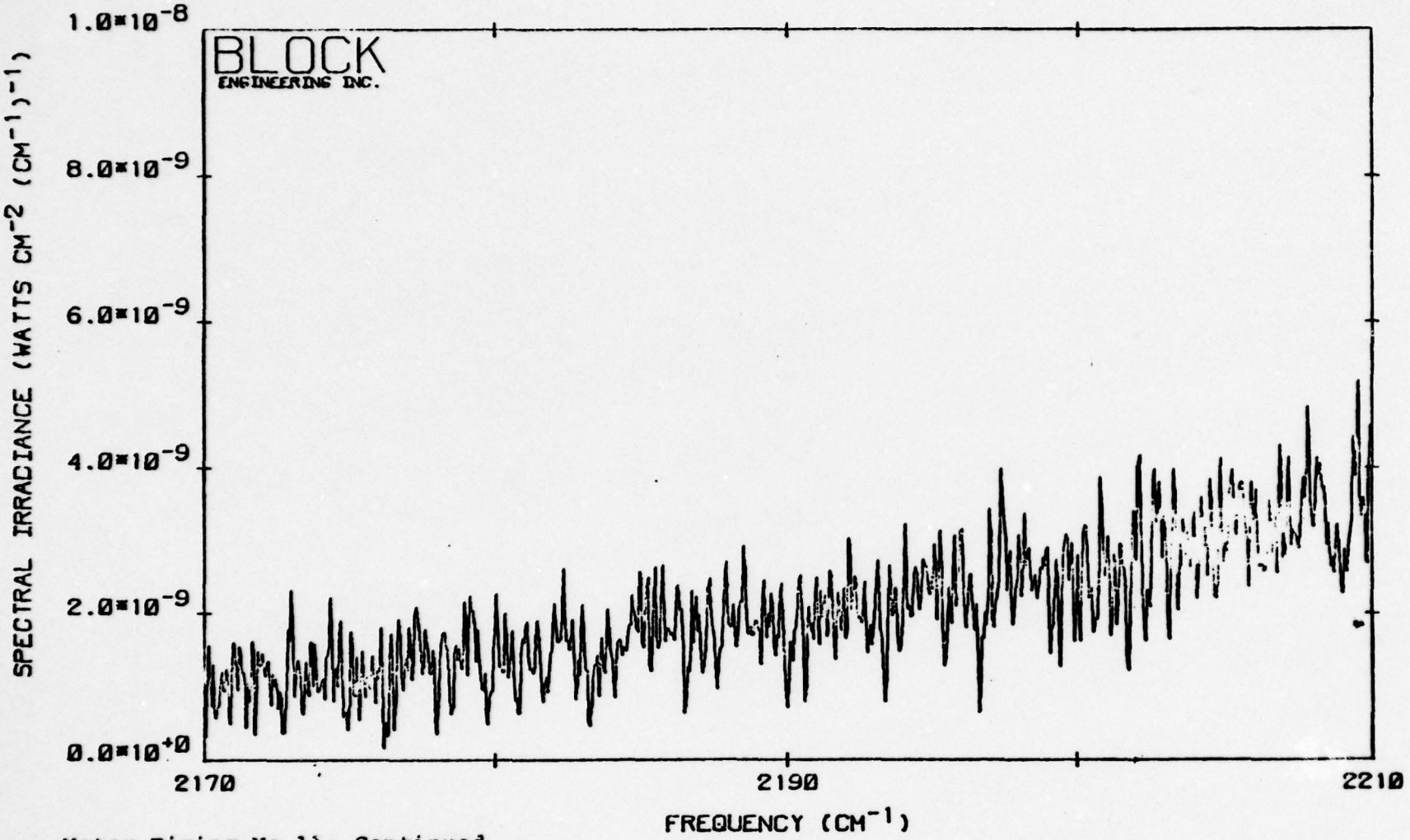
Motor Firing No.11; 4.57 km Altitude; 15 cm From Exit Plane



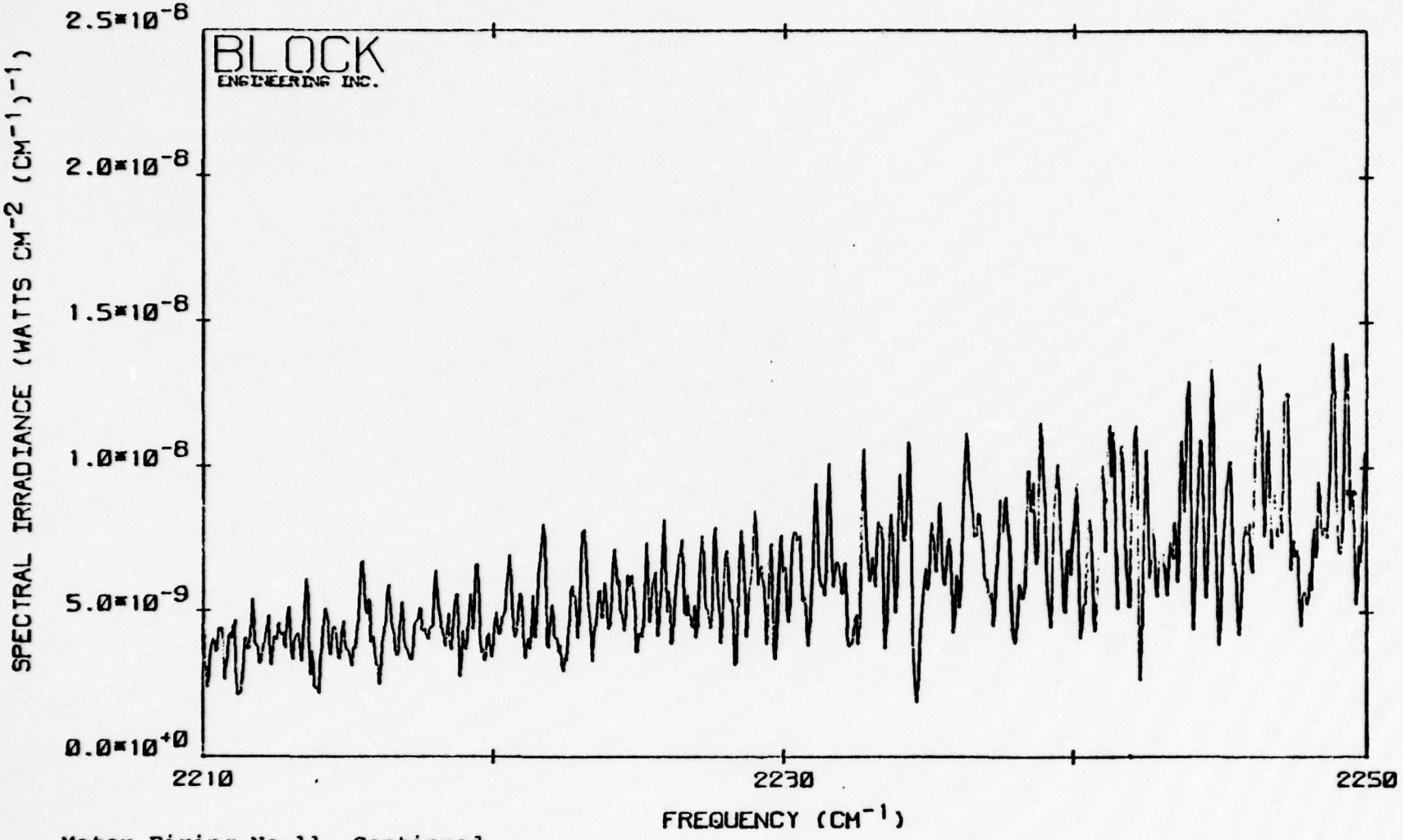
Motor Firing No.11; Continued



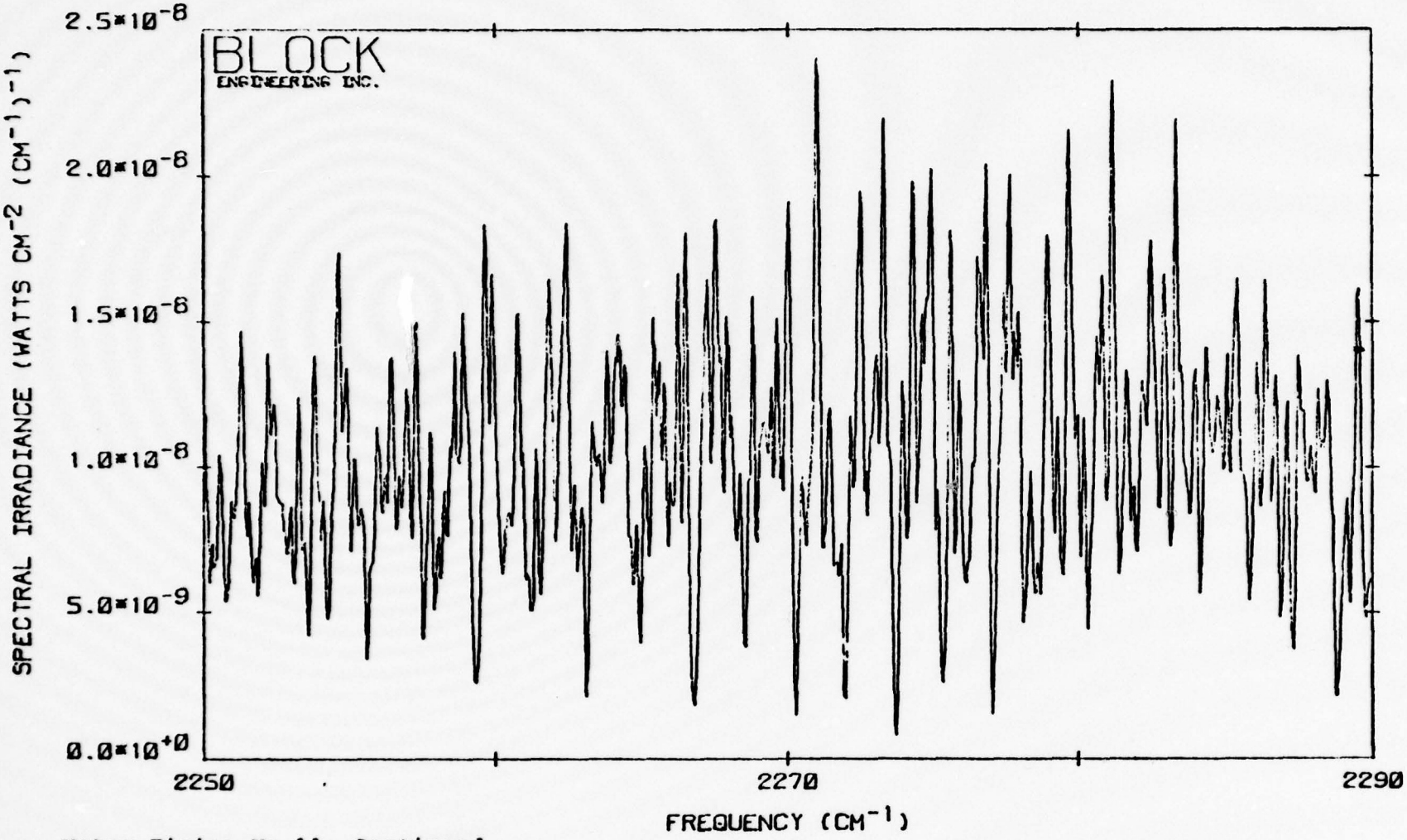
Motor Firing No.11; Continued



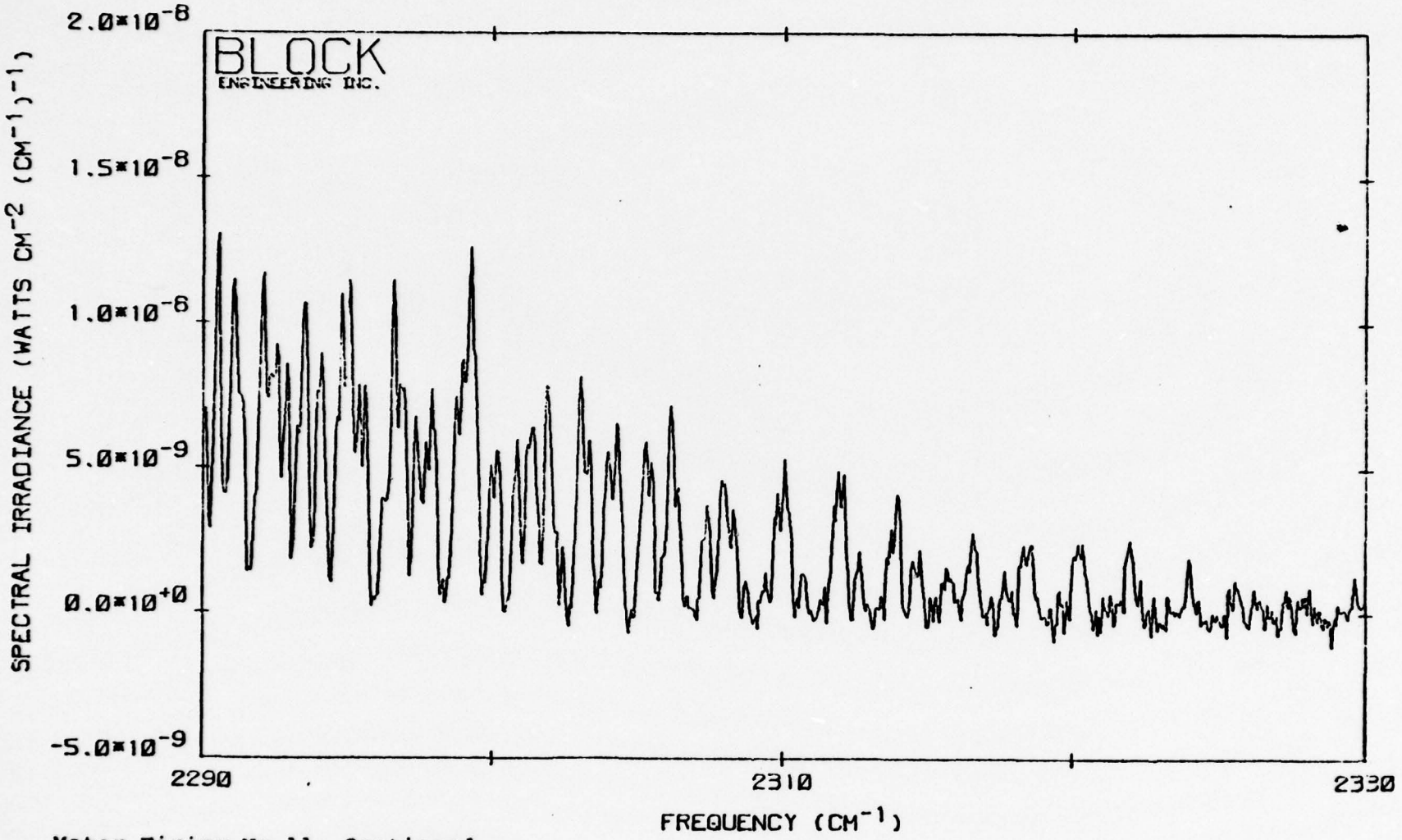
Motor Firing No.11; Continued



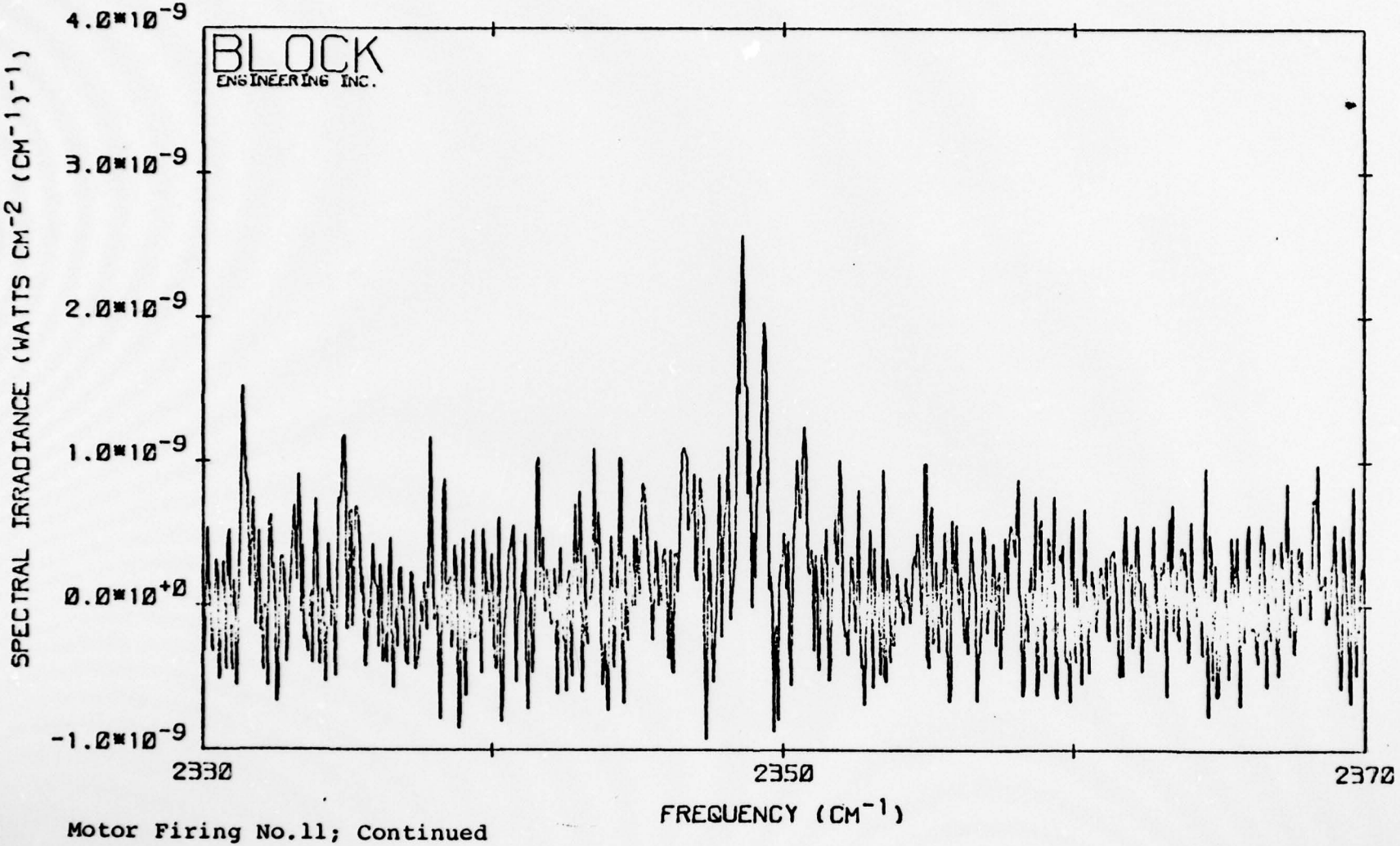
Motor Firing No.11; Continued



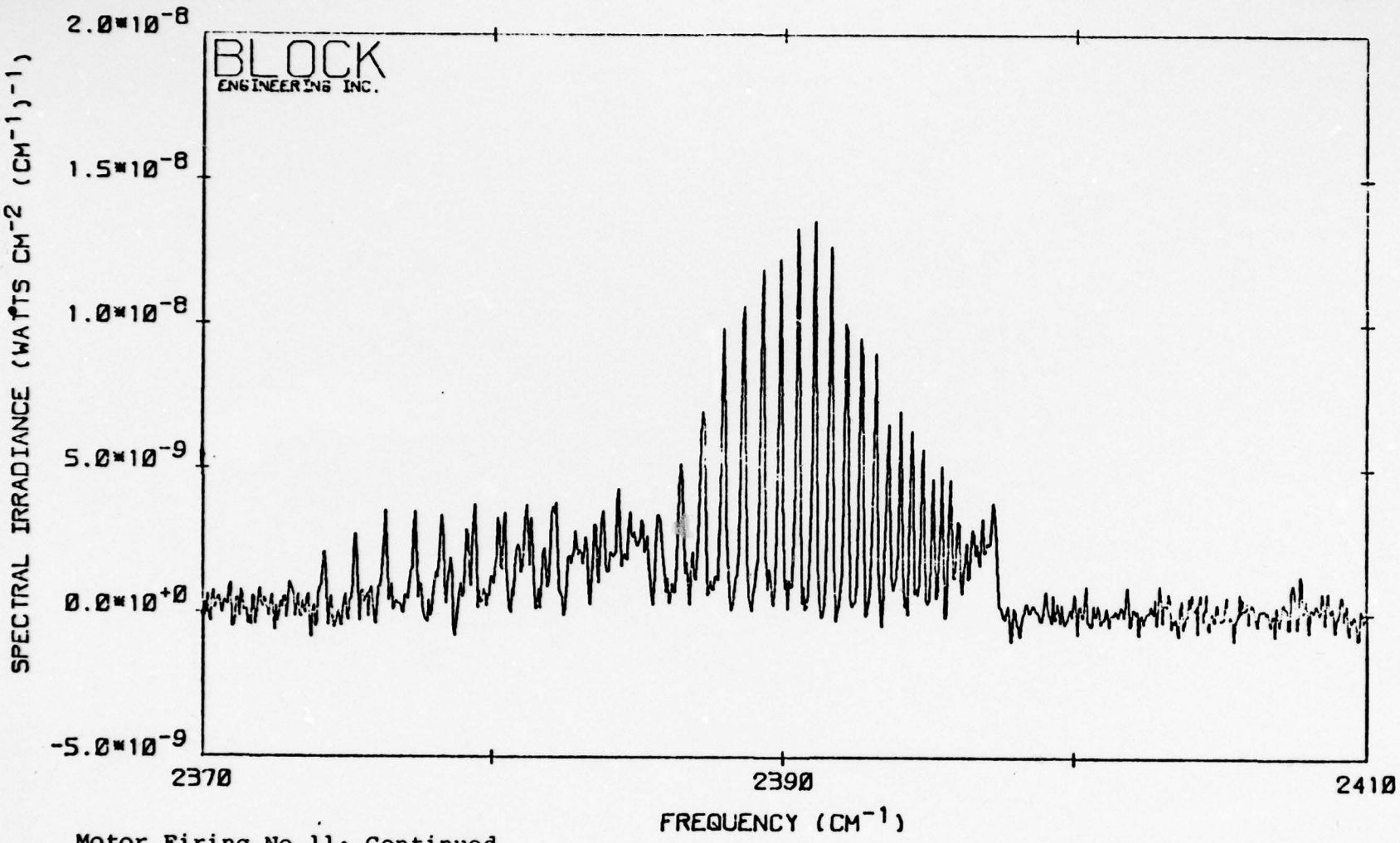
Motor Firing No.11; Continued



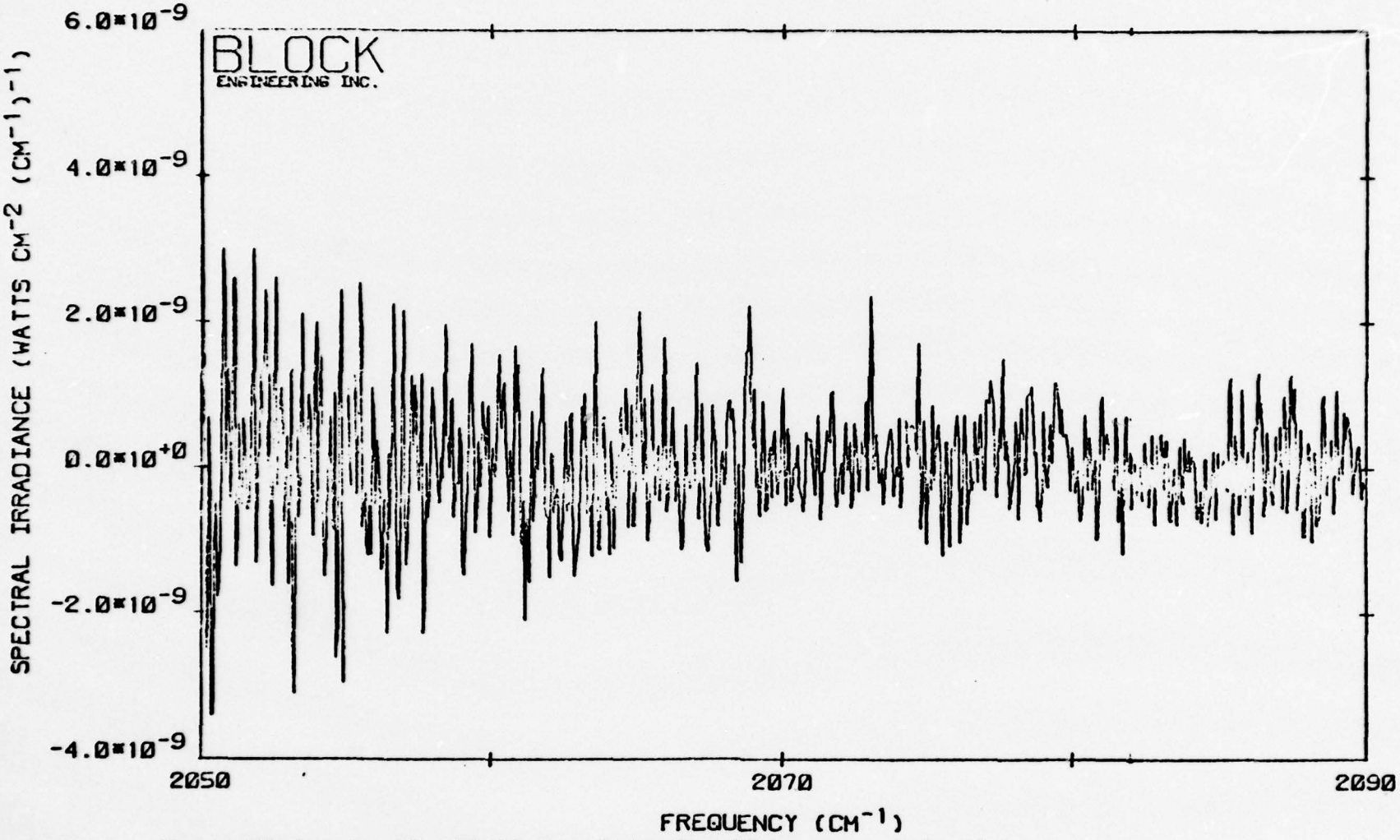
Motor Firing No.11; Continued



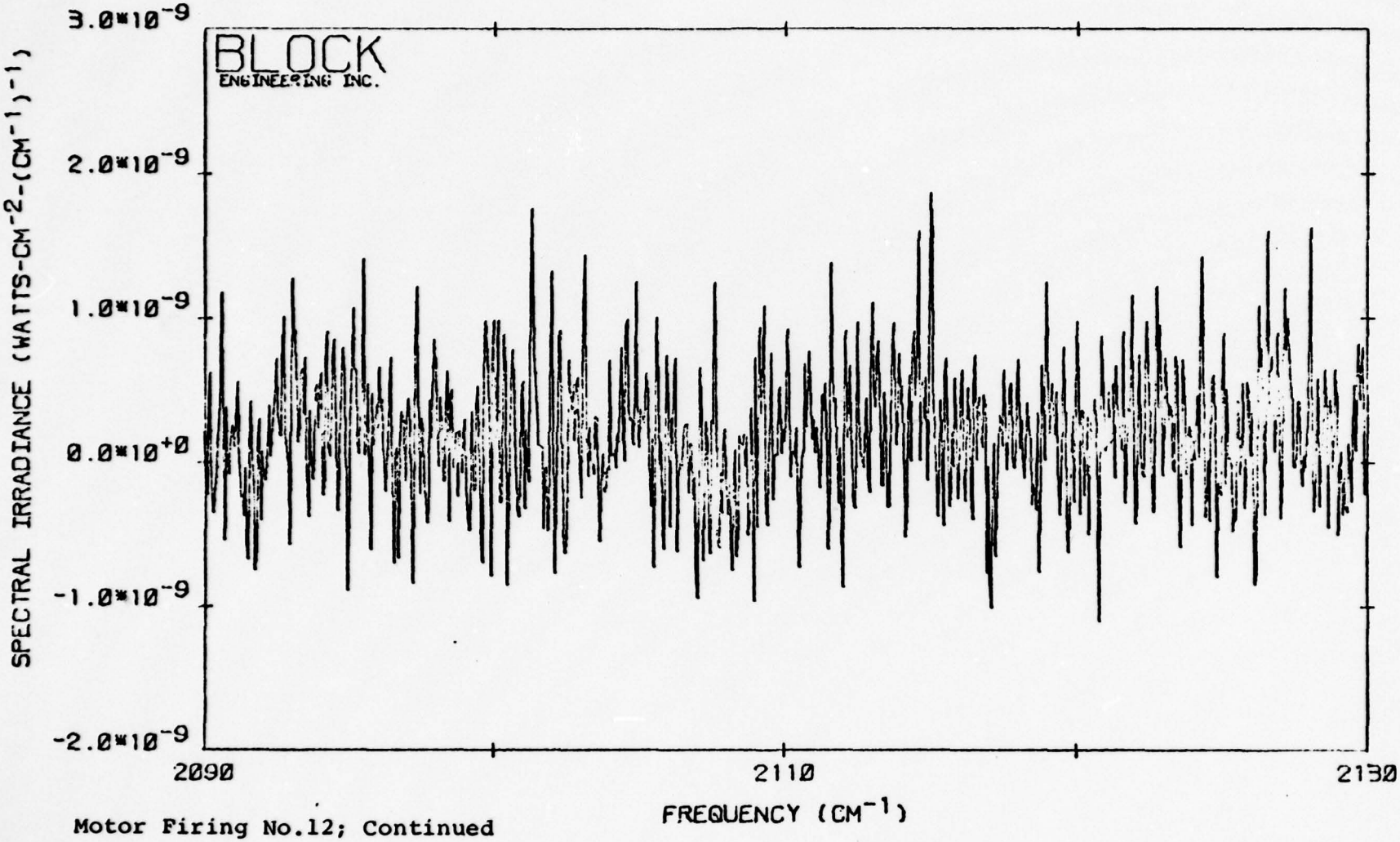
Motor Firing No.11; Continued



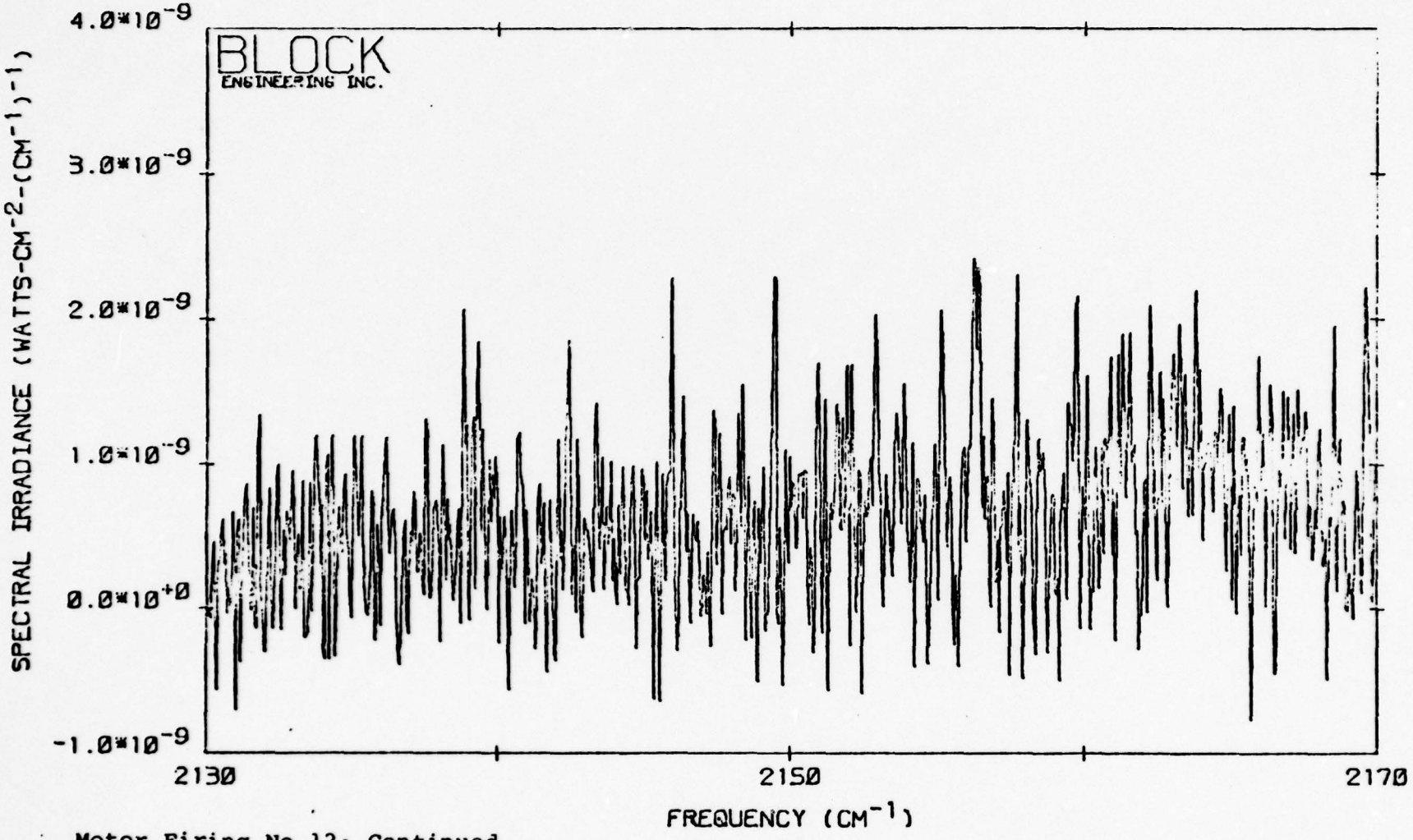
Motor Firing No.11; Continued



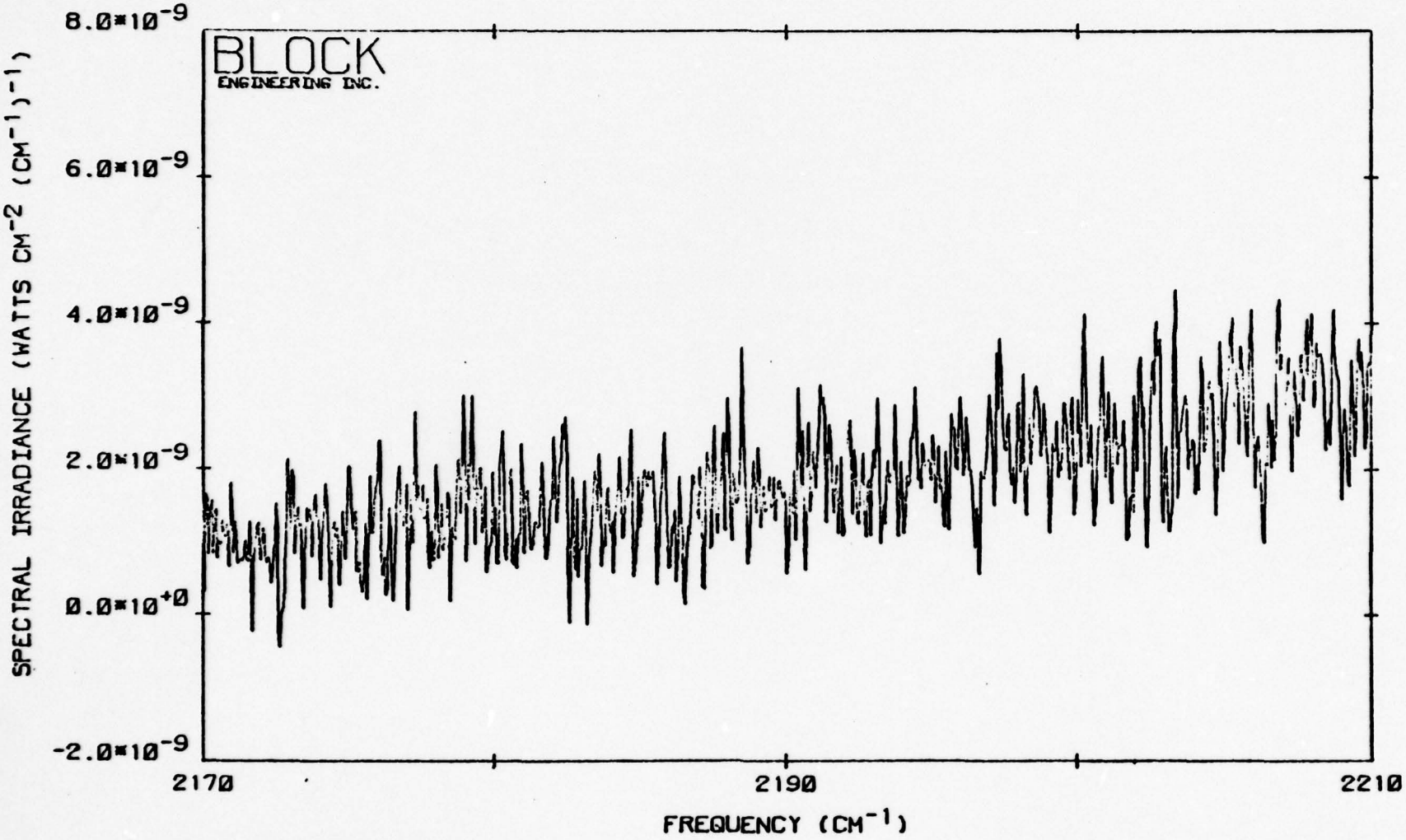
Motor Firing No.12; 12.19 km Altitude; 15 cm From Exit Plane



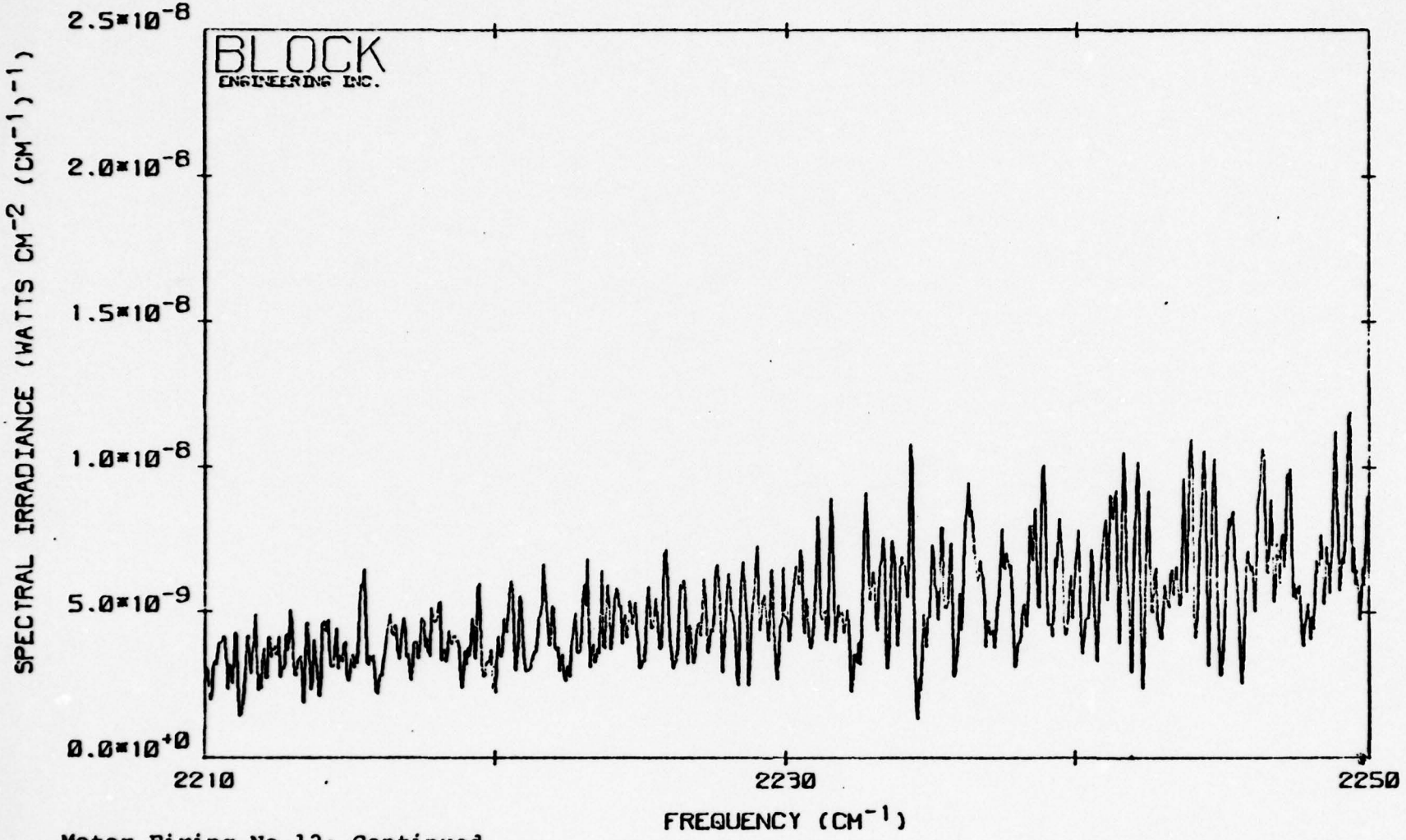
Motor Firing No.12; Continued



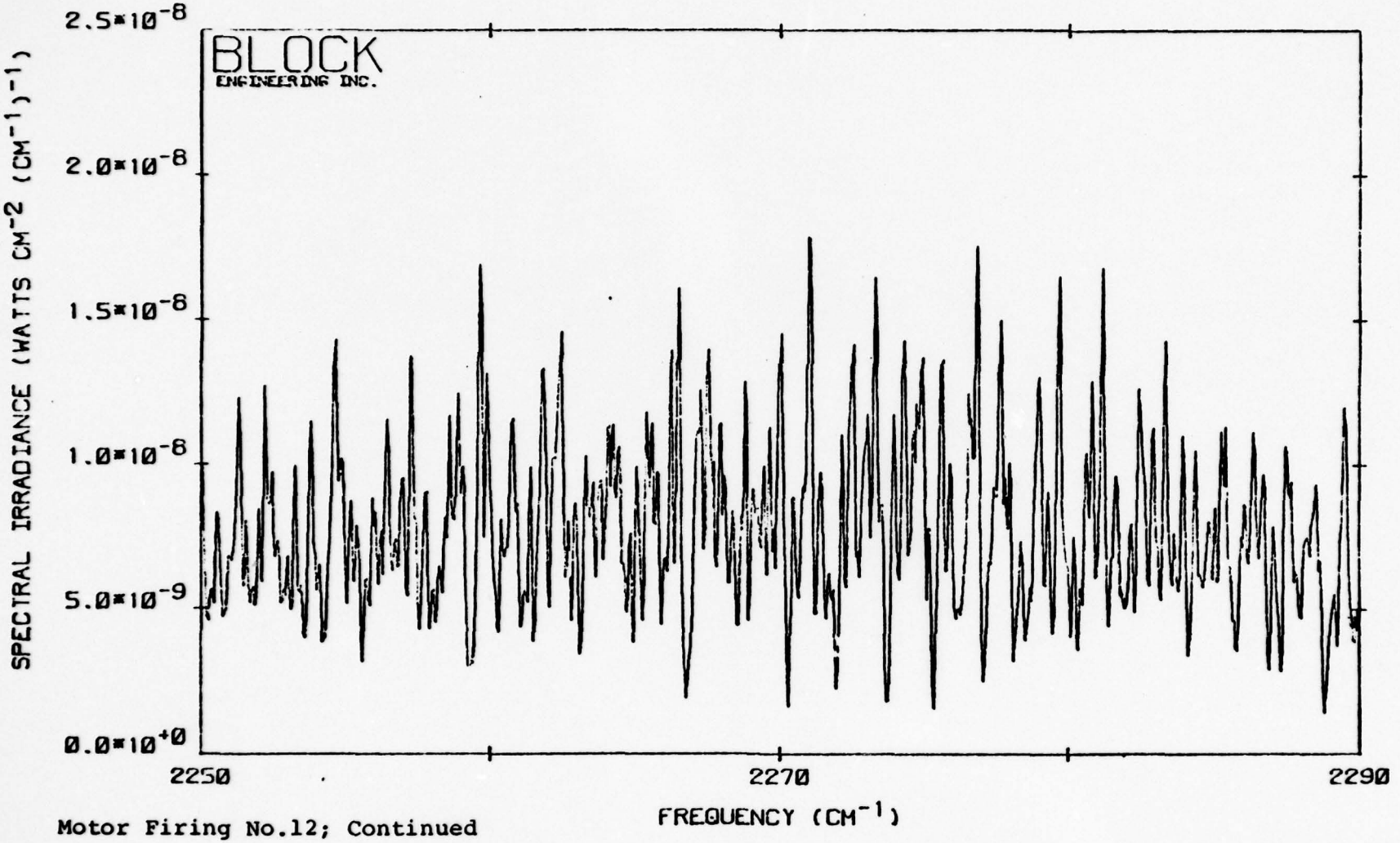
Motor Firing No.12; Continued



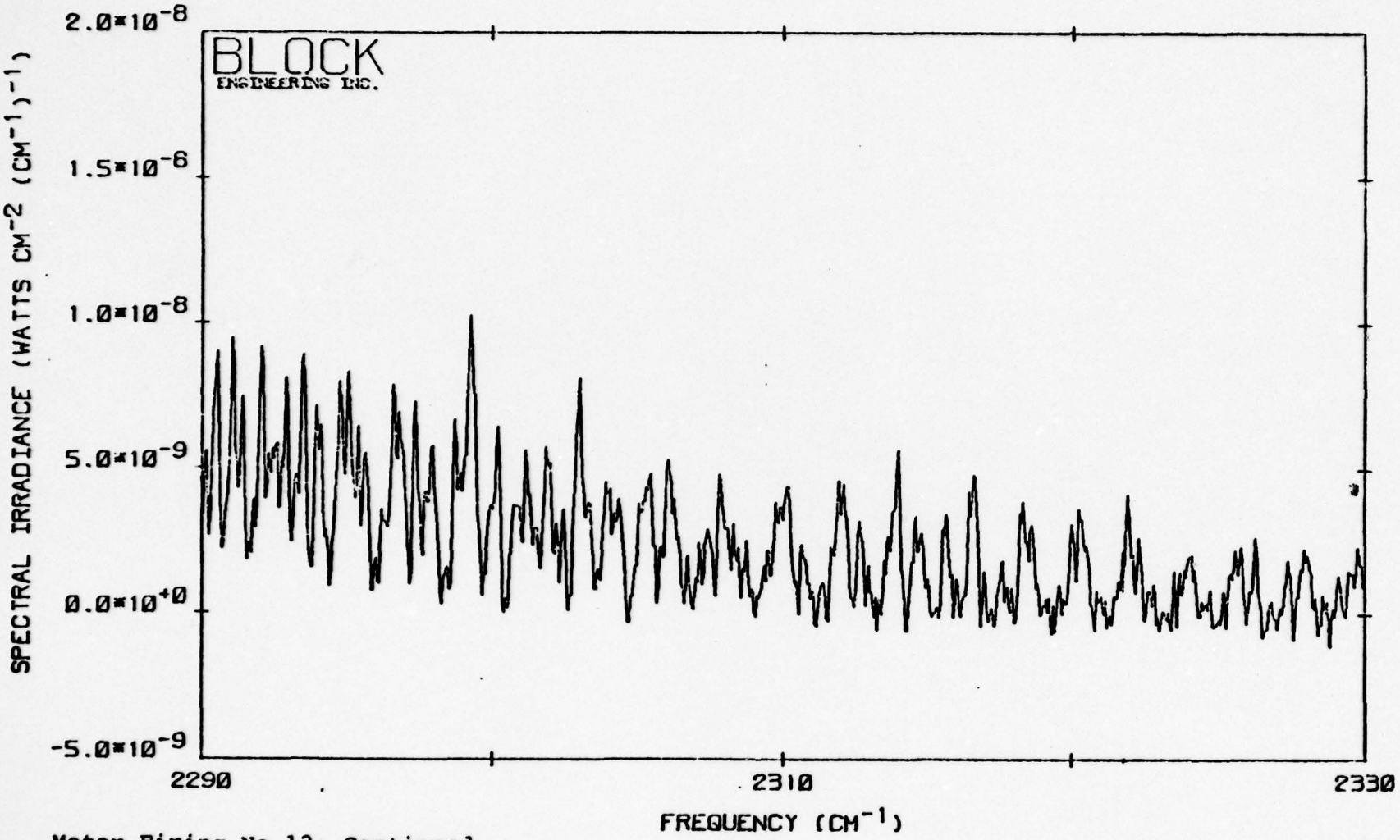
Motor Firing No.12; Continued



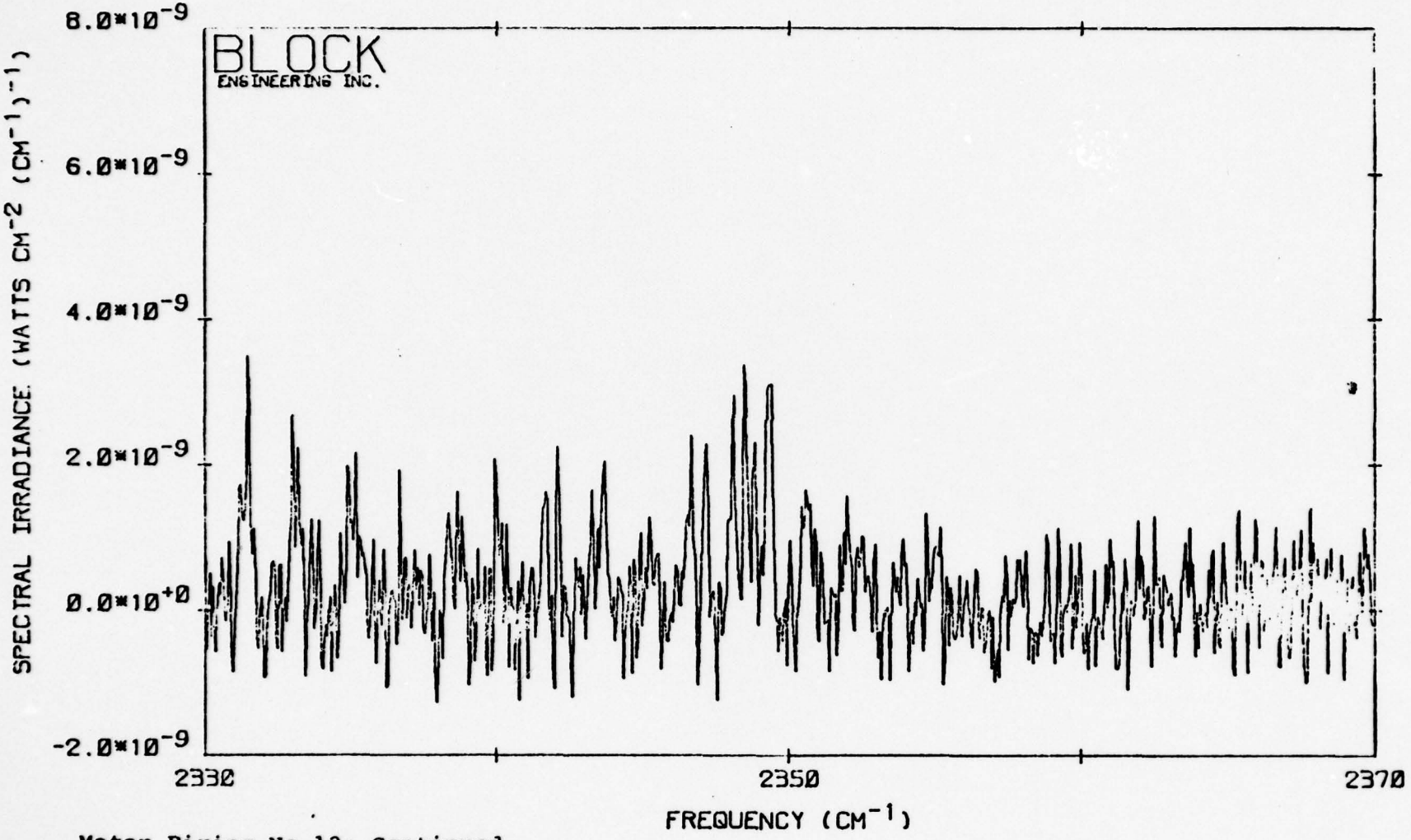
Motor Firing No.12; Continued



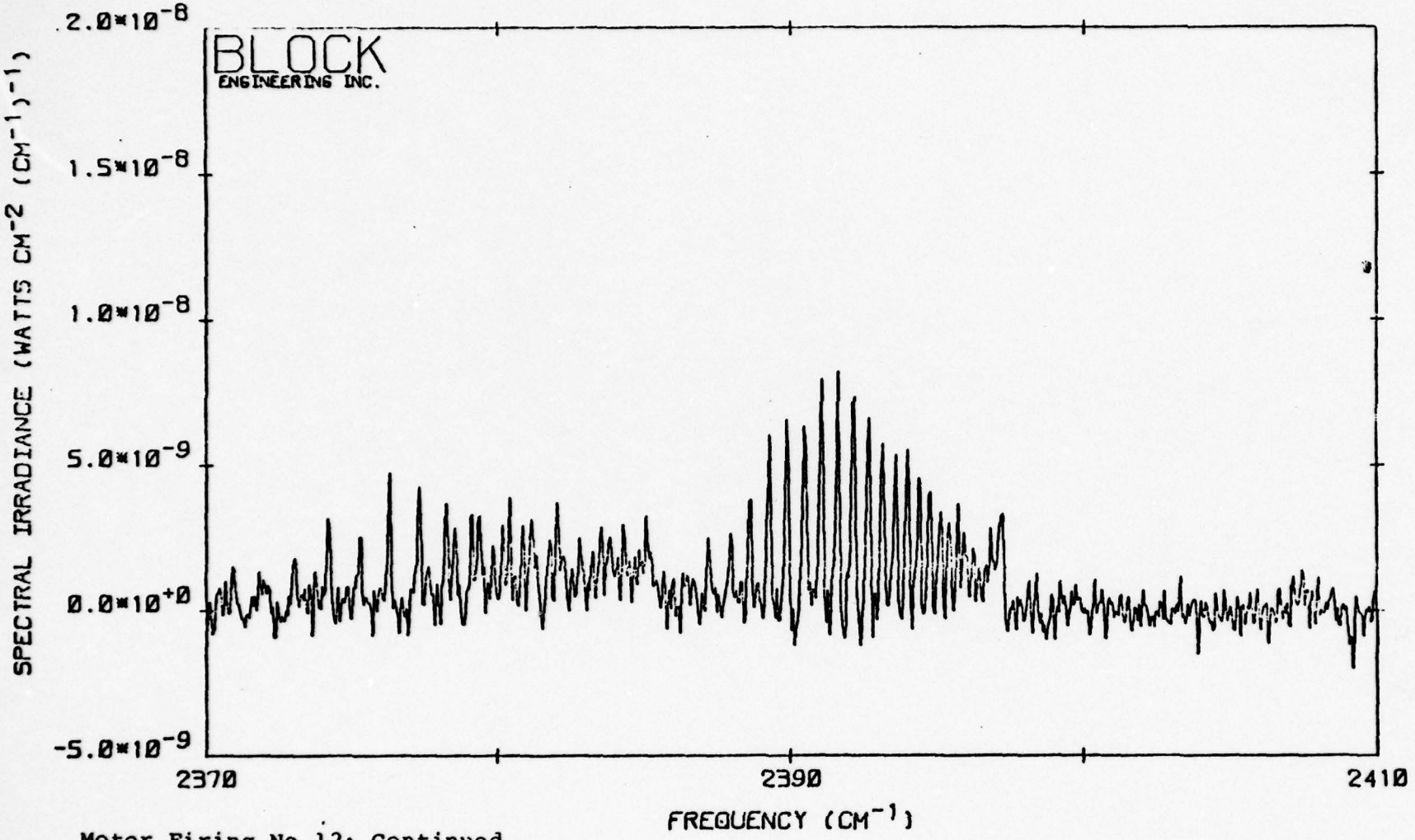
Motor Firing No.12; Continued



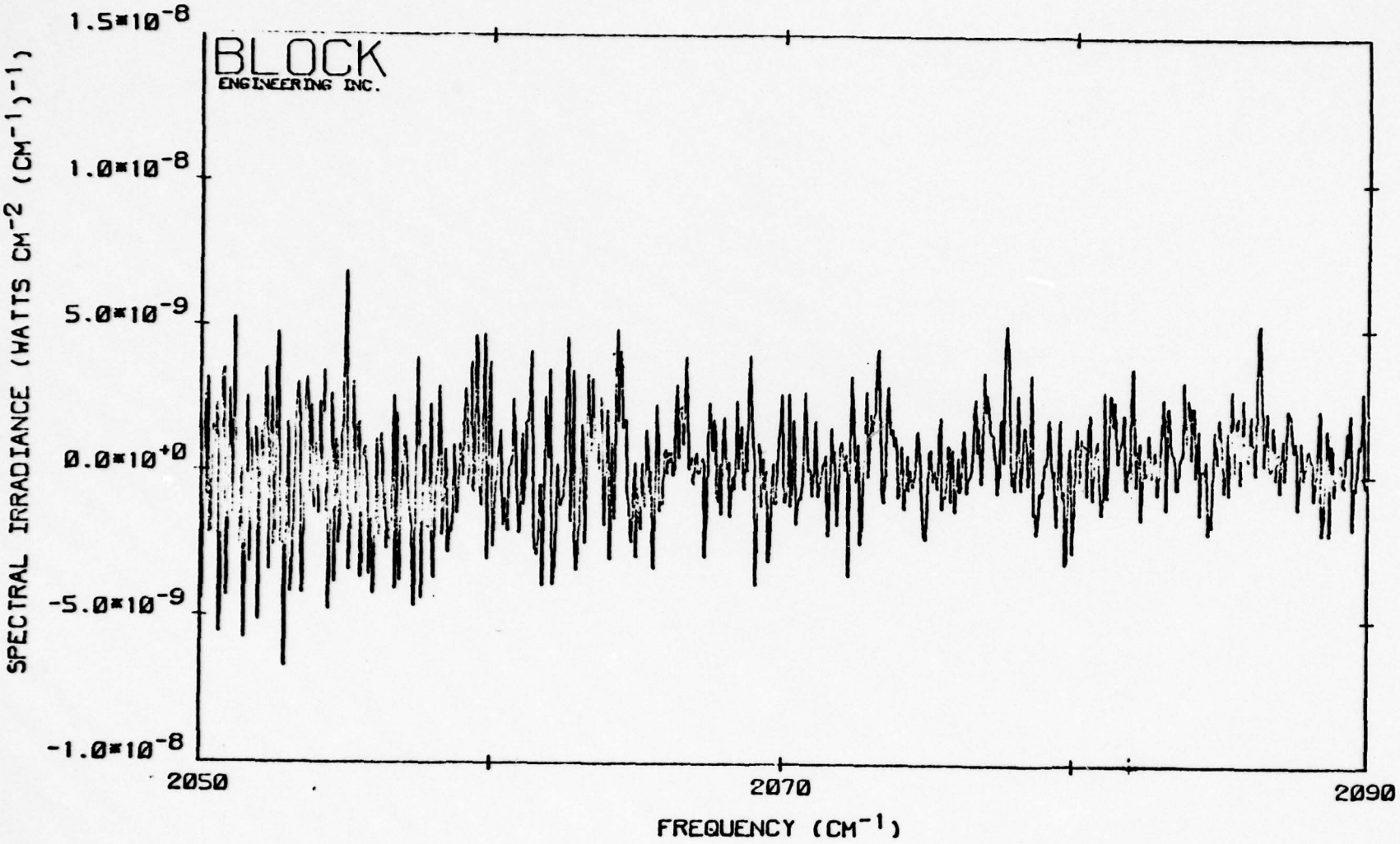
Motor Firing No.12; Continued



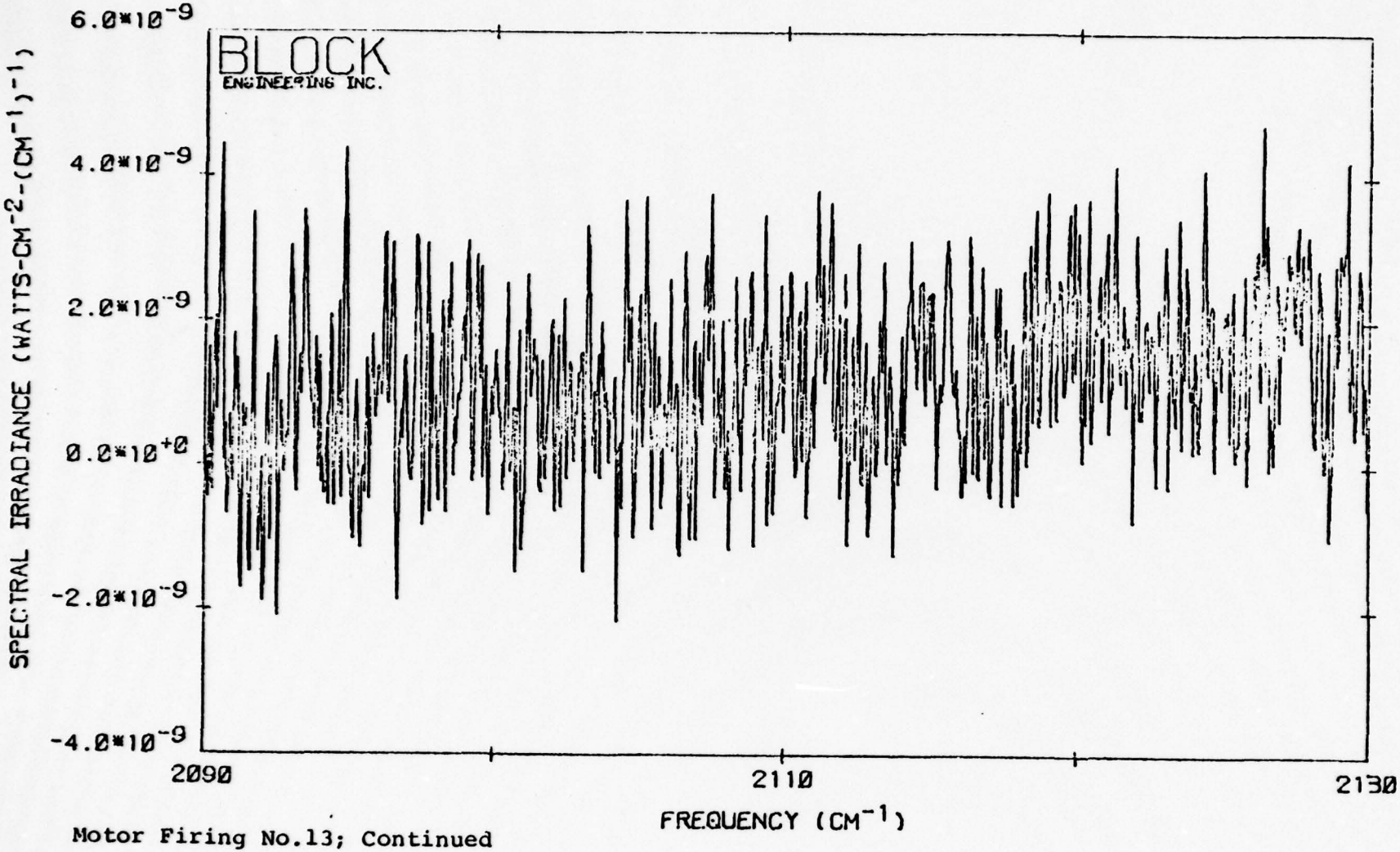
Motor Firing No.12; Continued



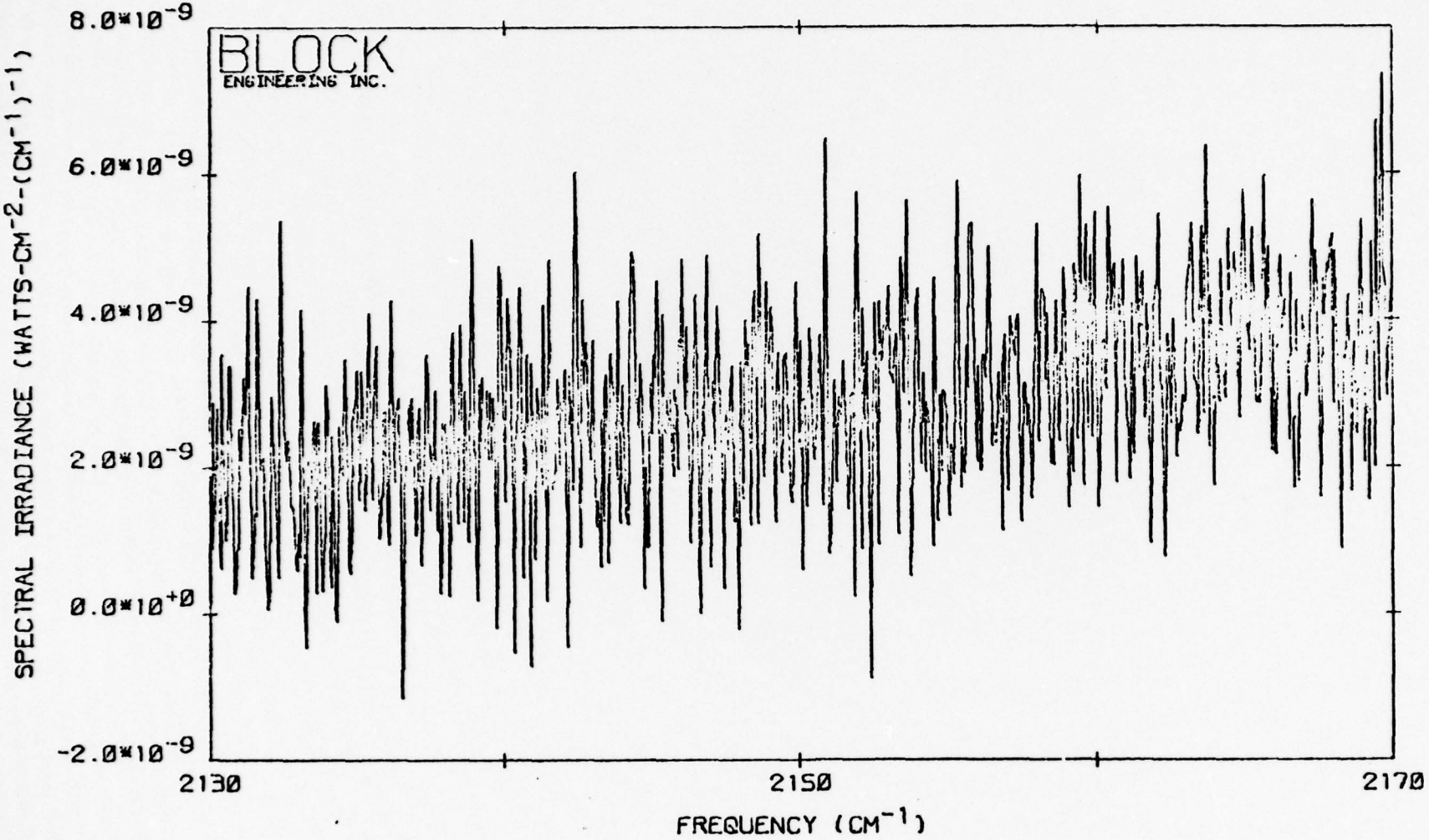
Motor Firing No.12; Continued



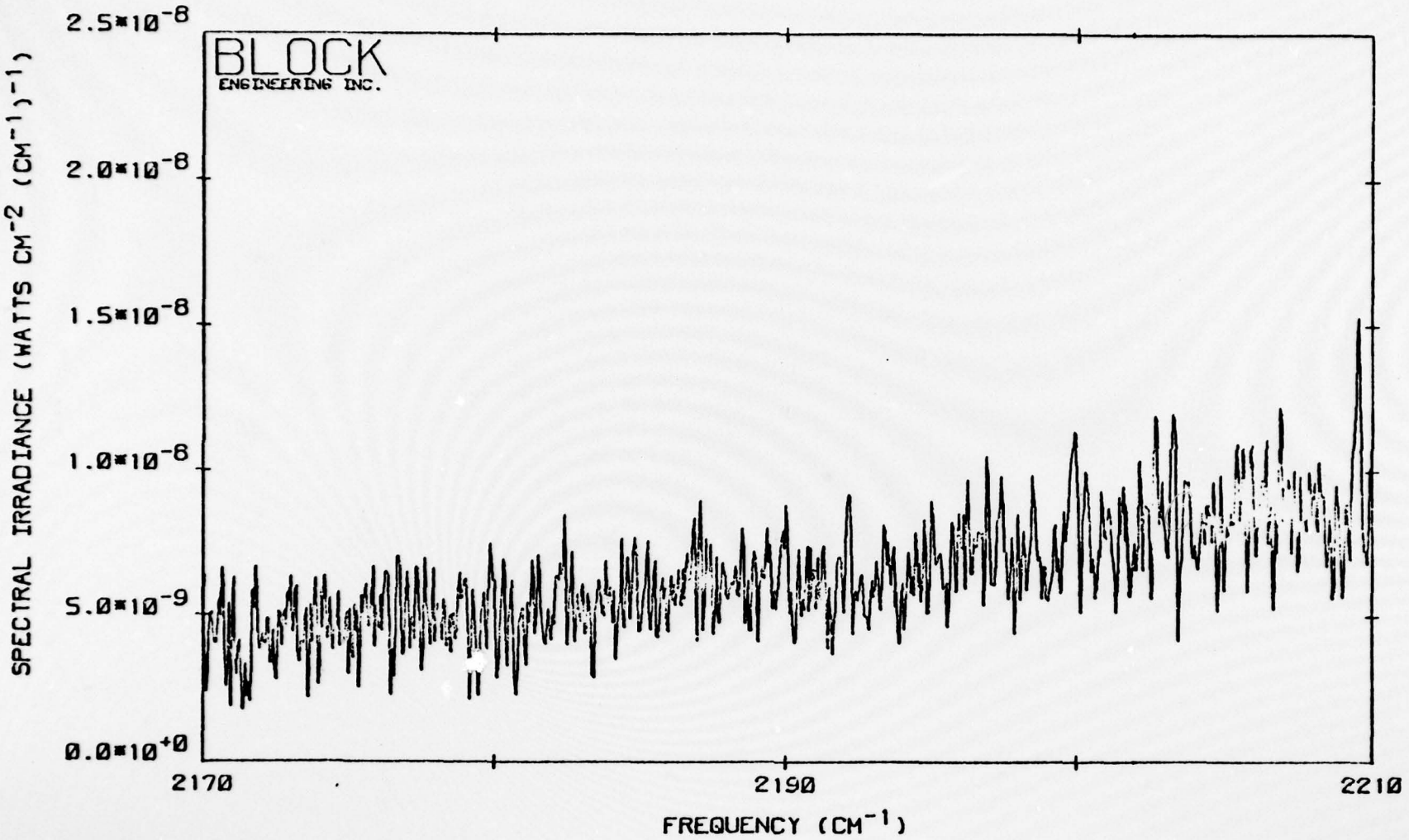
Motor Firing No.13; 0 km Altitude; 5 cm From Exit Plane



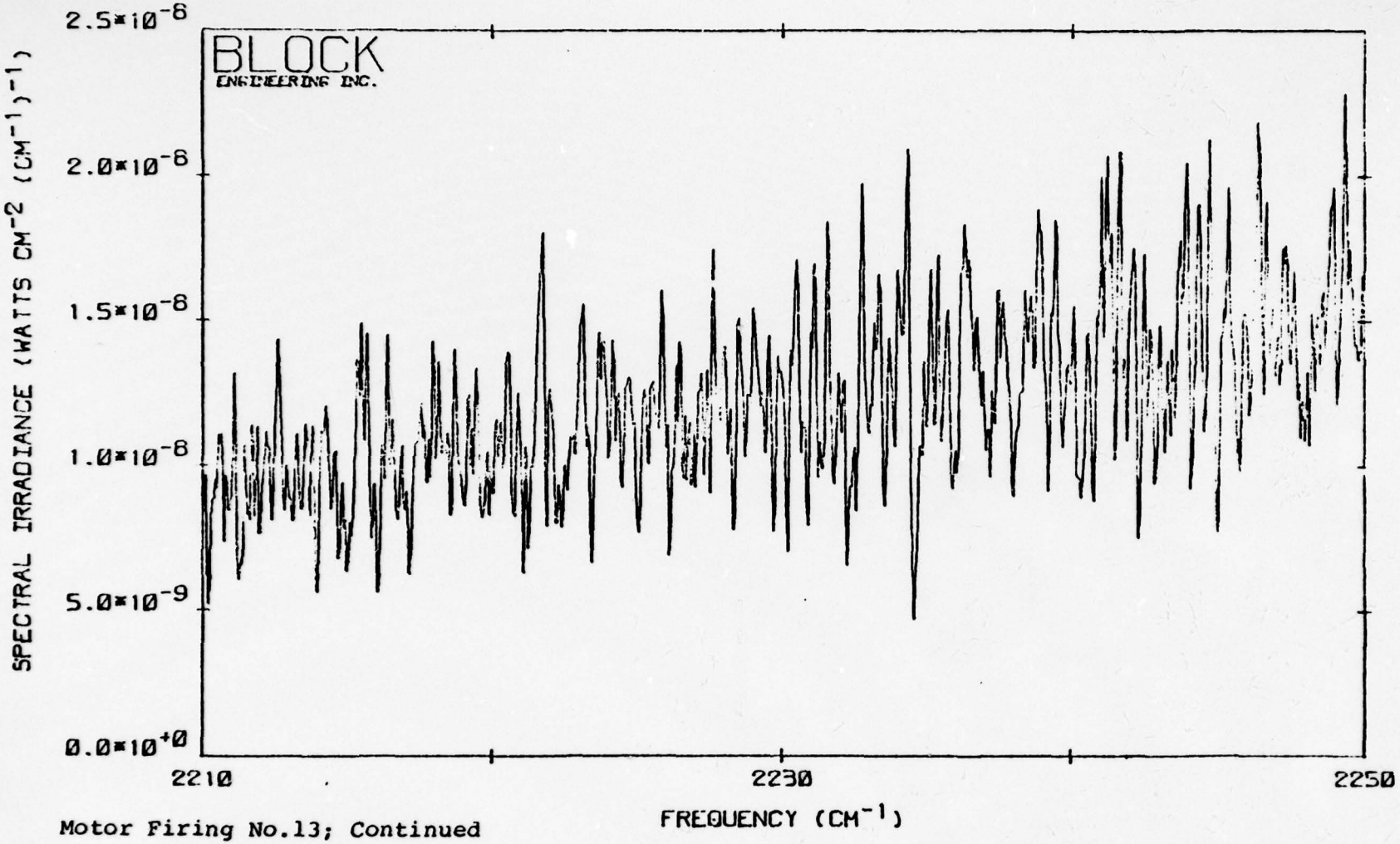
Motor Firing No.13; Continued



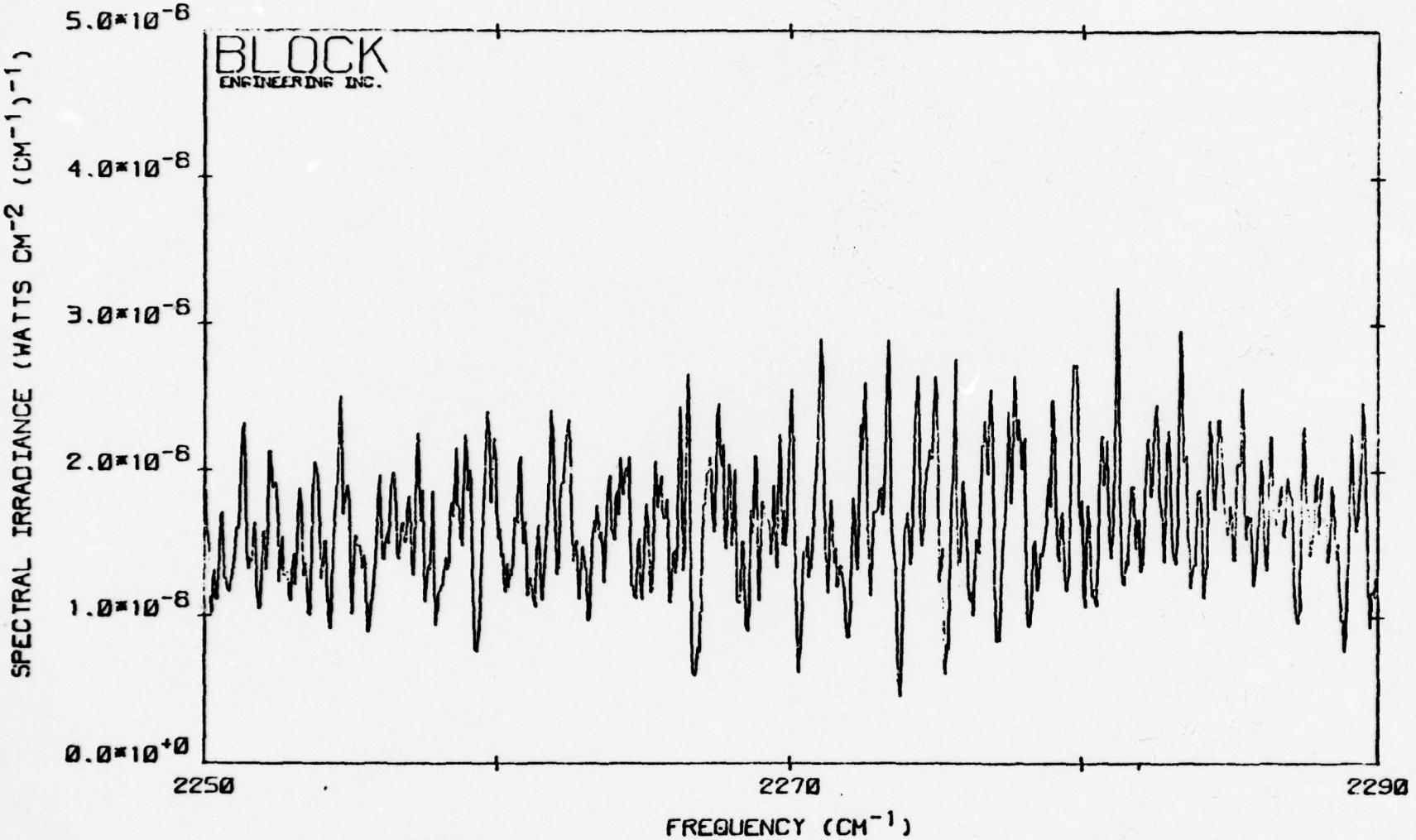
Motor Firing No.13; Continued



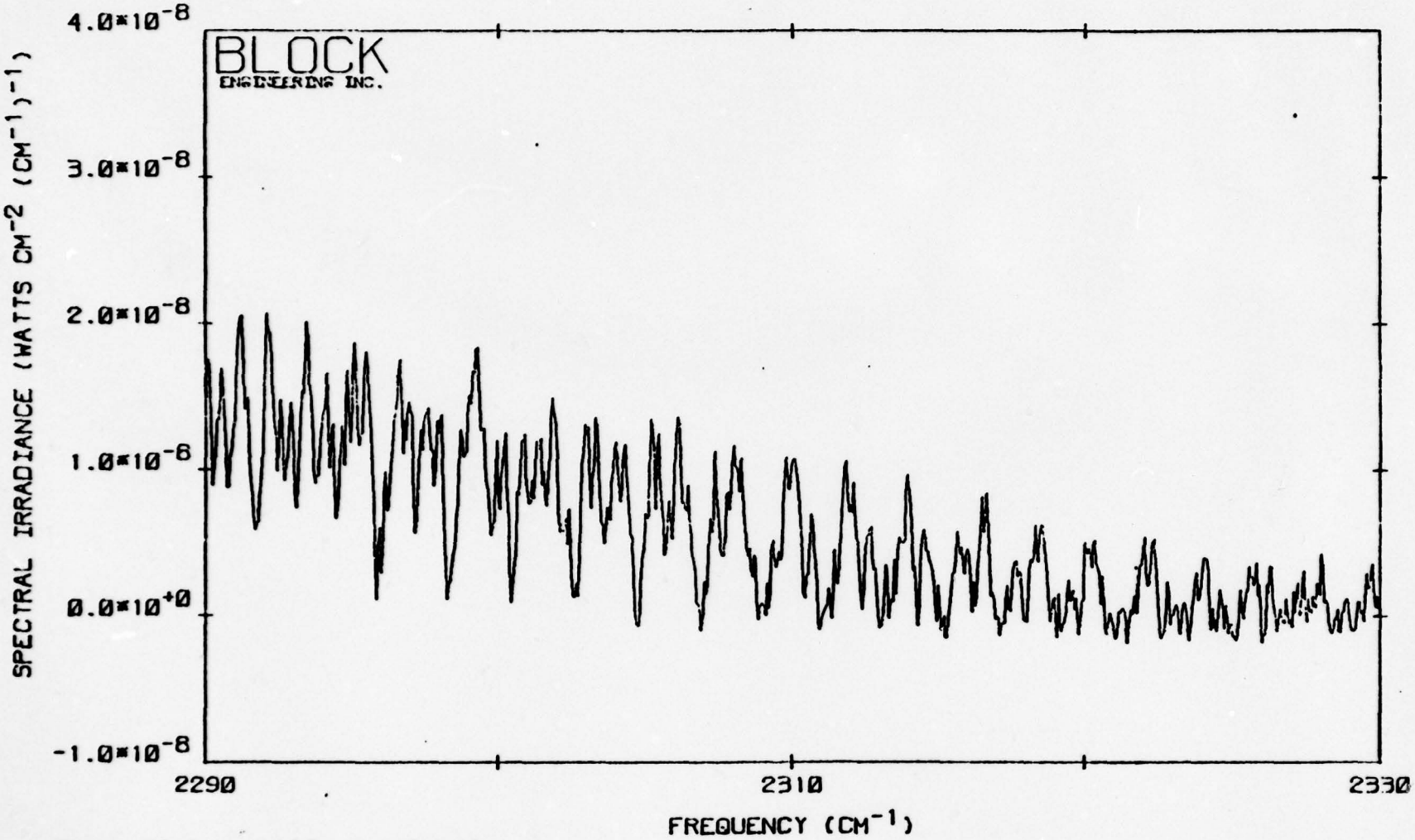
Motor Firing No.13; Continued



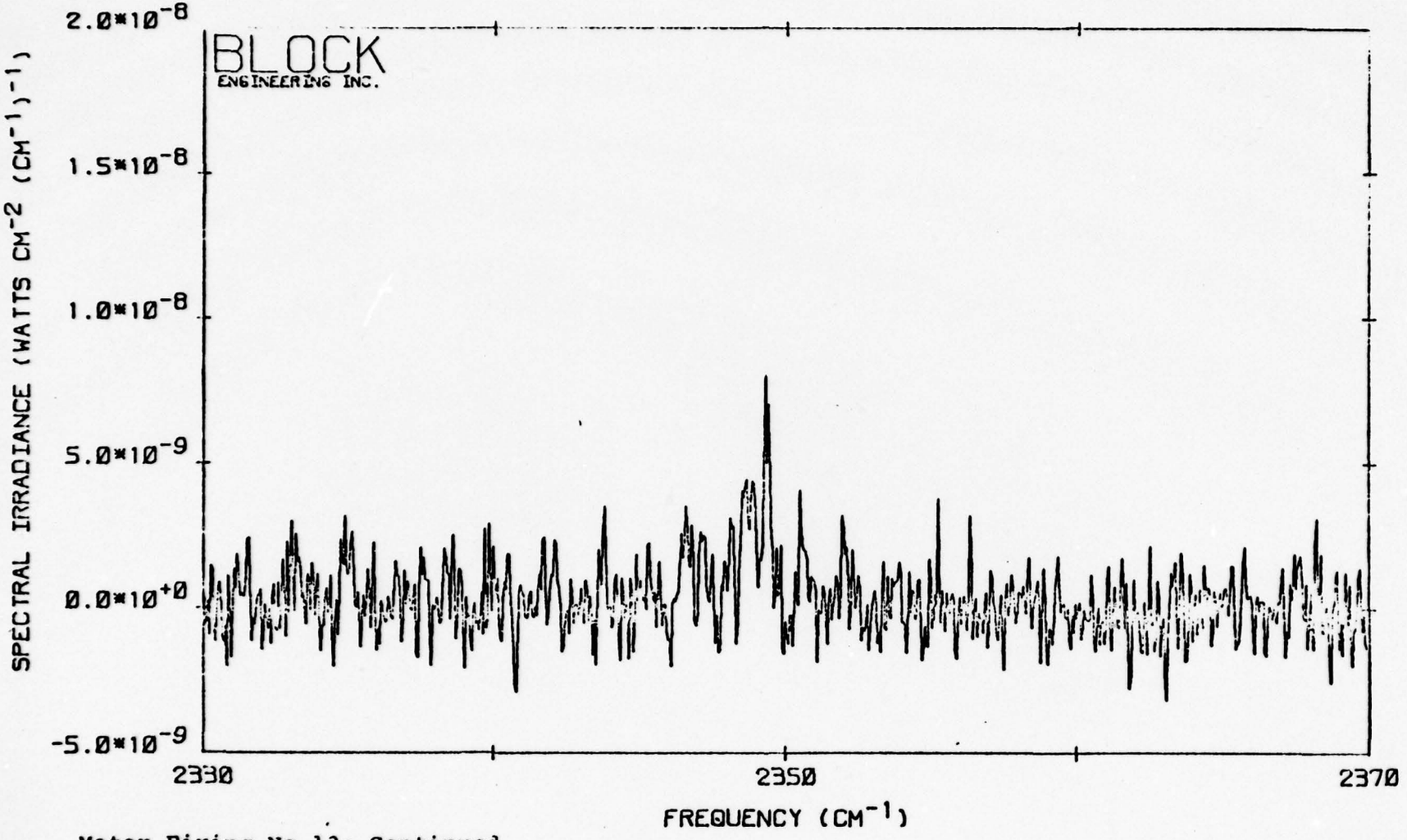
Motor Firing No.13; Continued



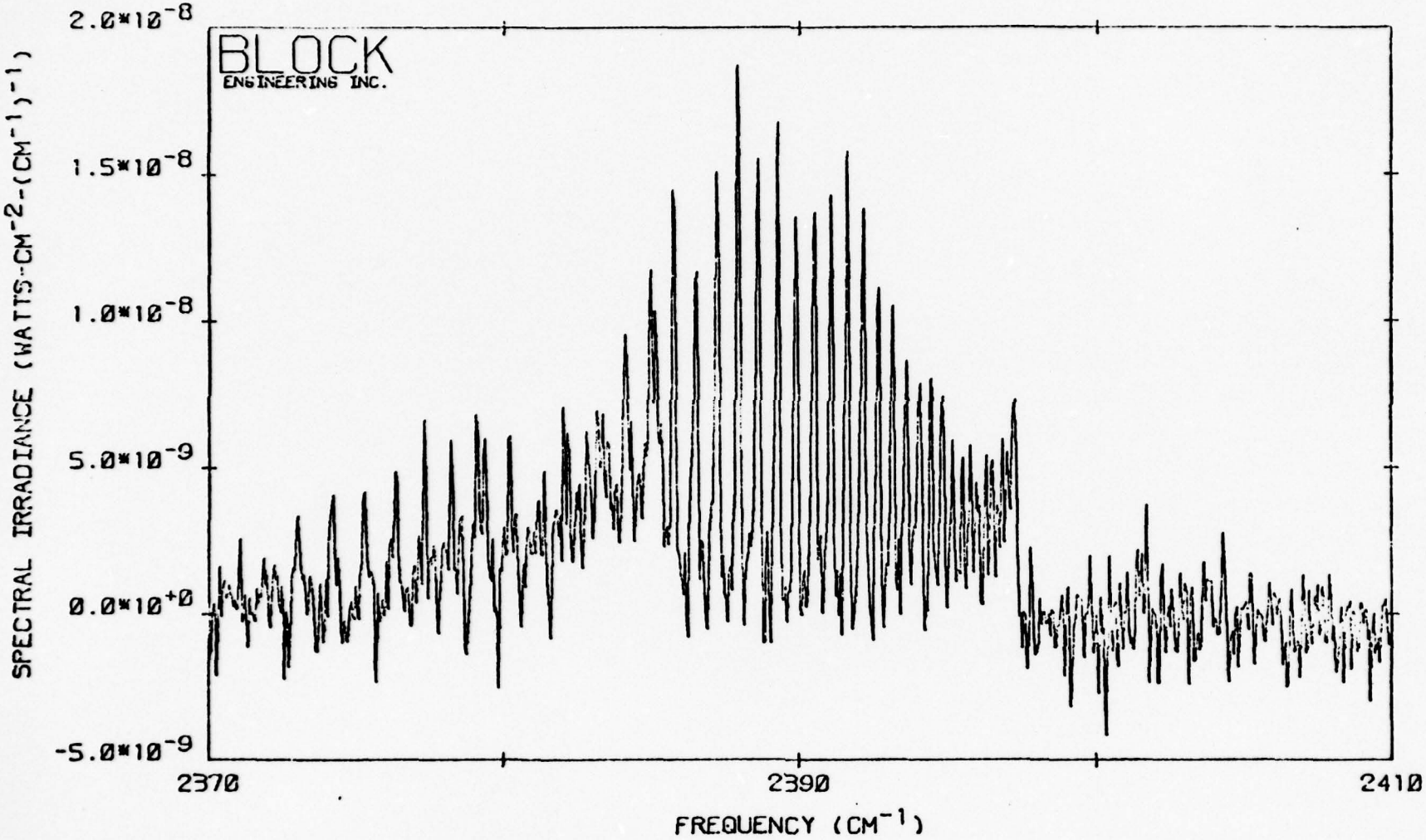
Motor Firing No.13; Continued



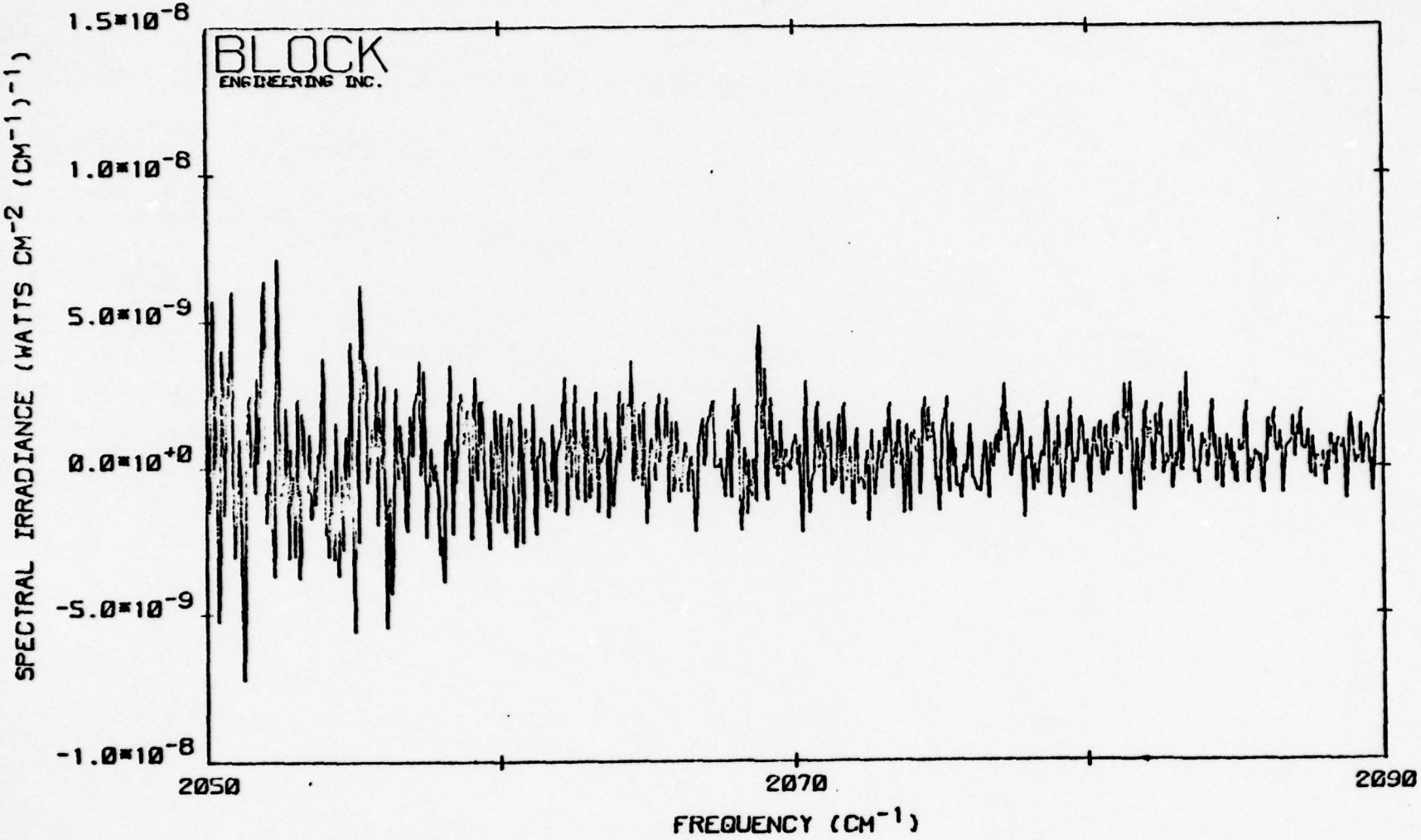
Motor Firing No.13; Continued



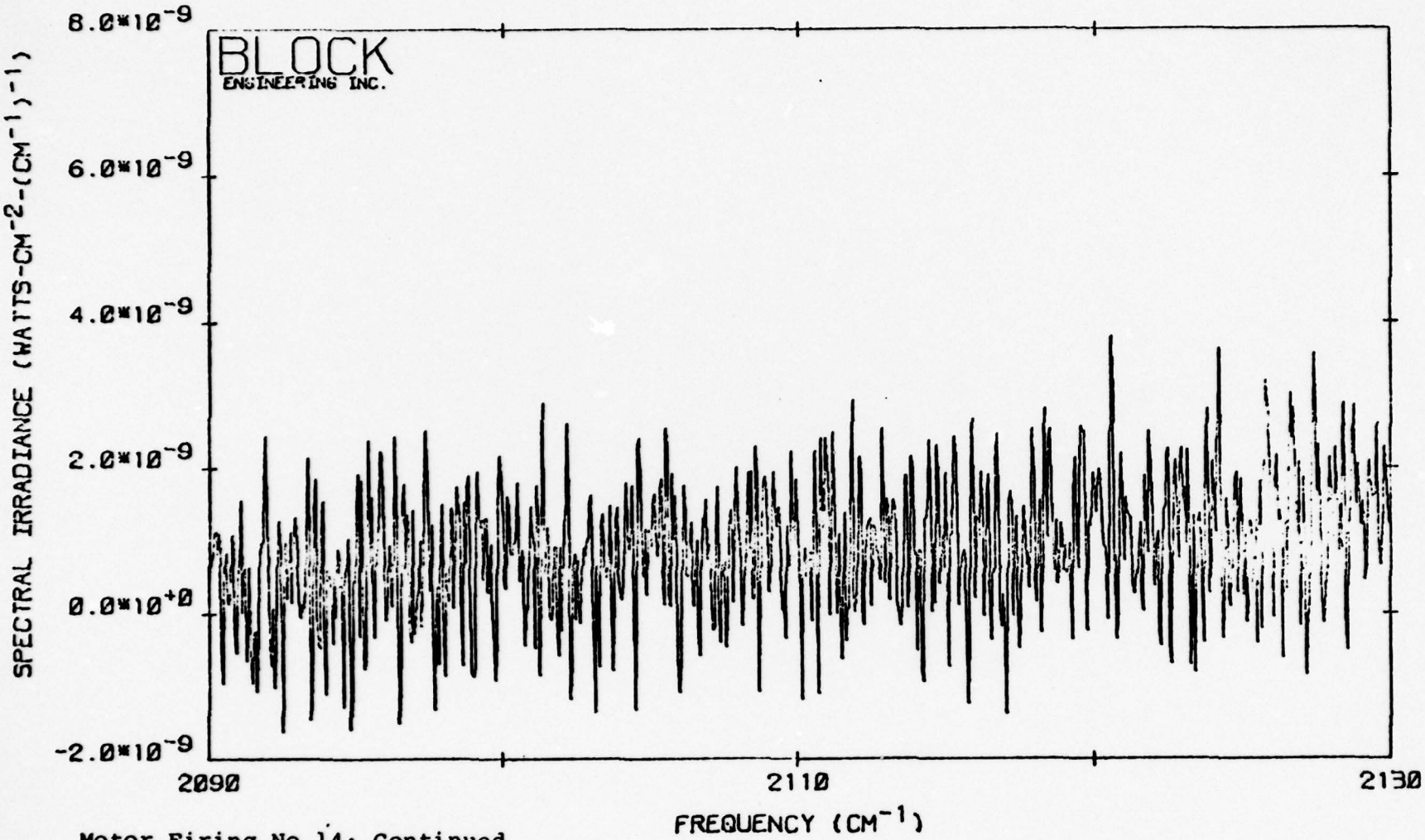
Motor Firing No.13; Continued



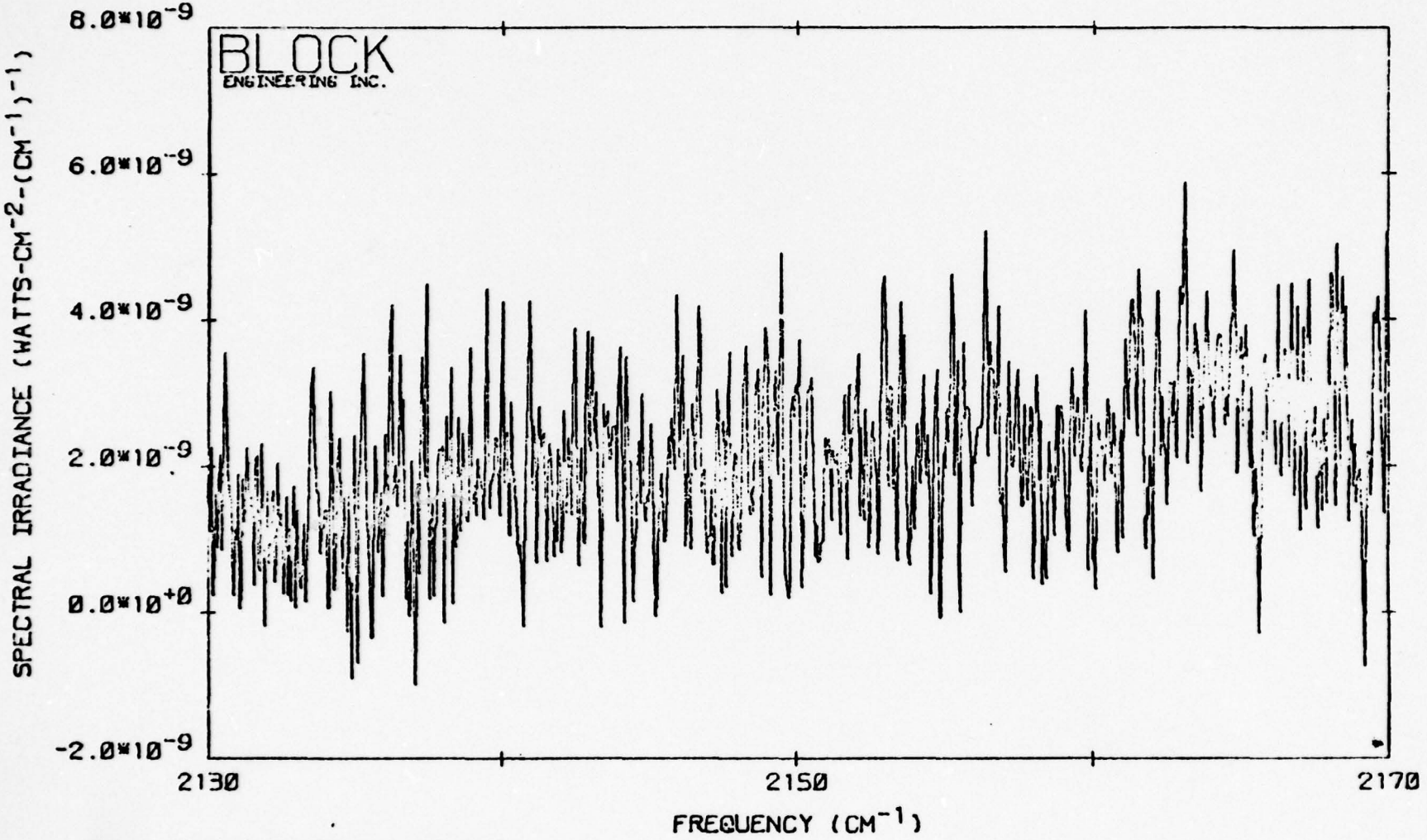
Motor Firing No.13; Continued



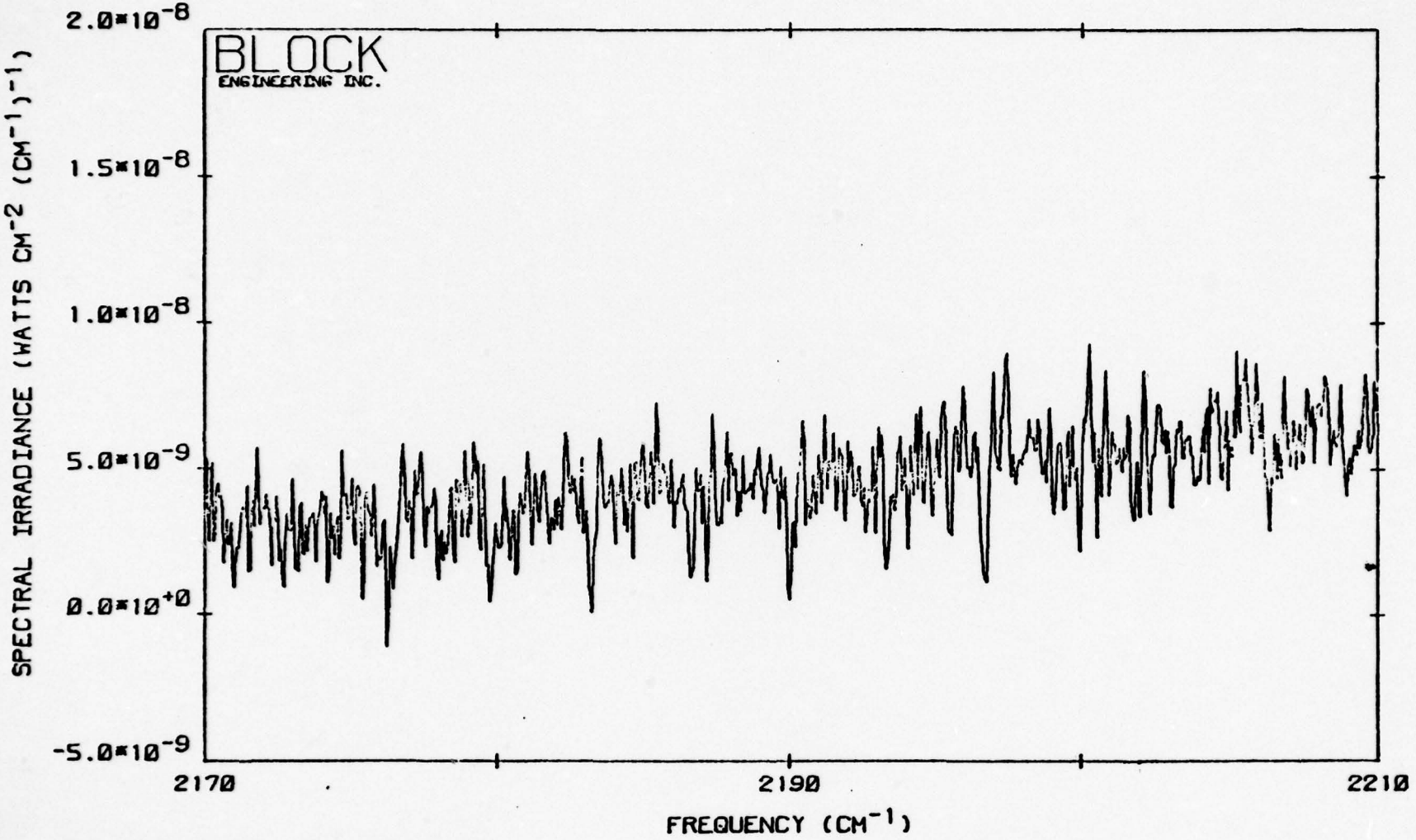
Motor Firing No.14; 4.57 km Altitude; 5 cm From Exit Plane



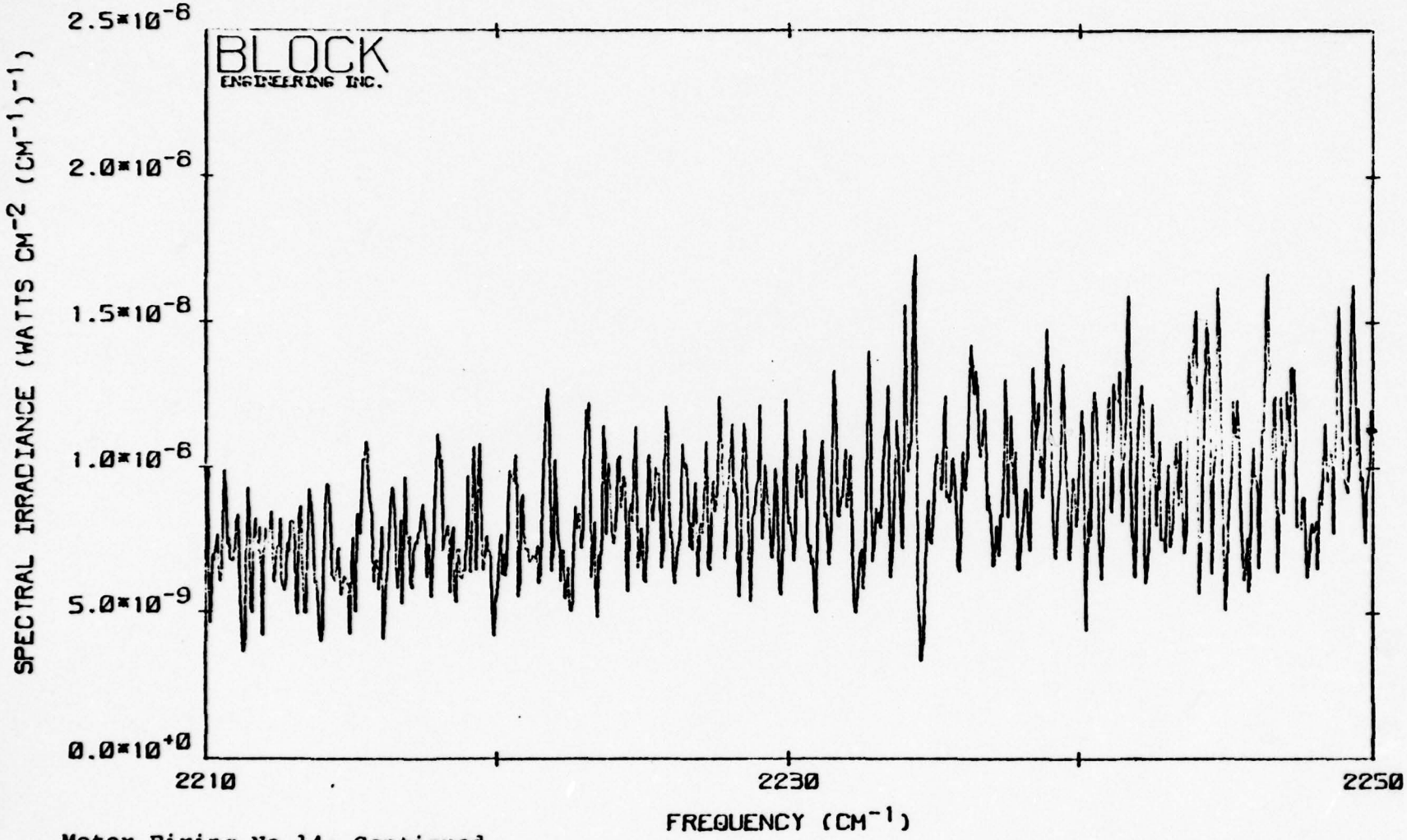
Motor Firing No.14; Continued



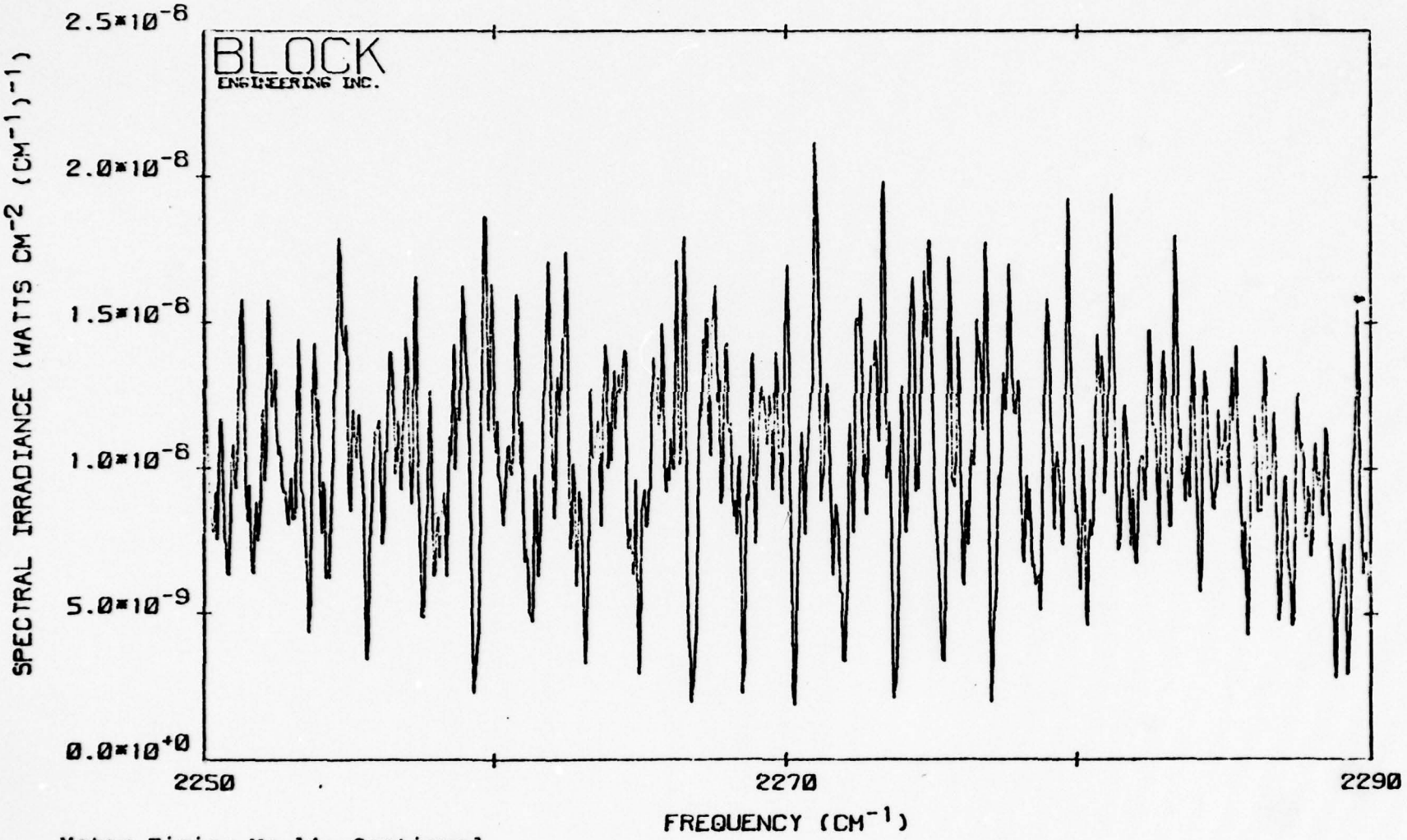
Motor Firing No.14; Continued



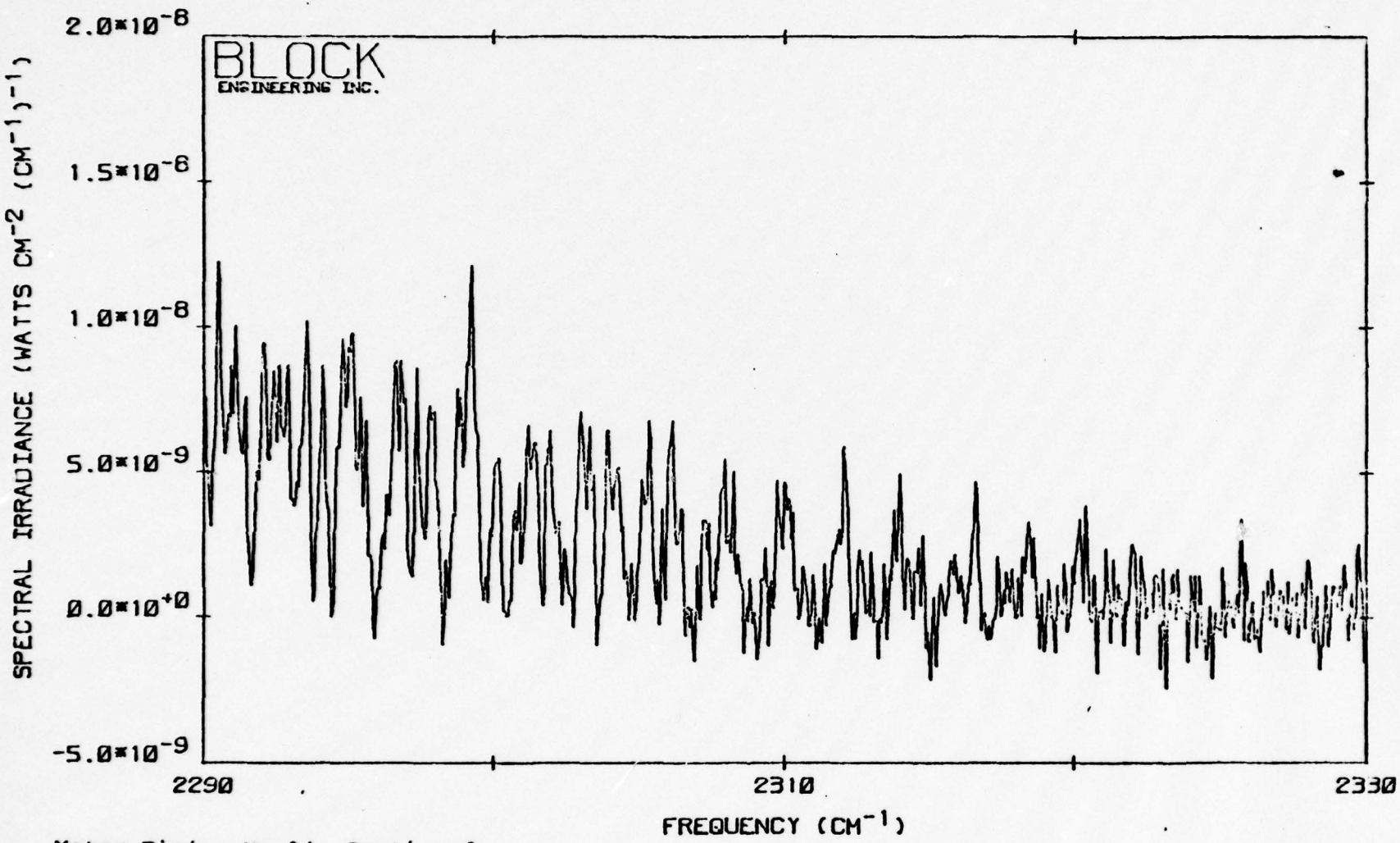
Motor Firing No.14; Continued



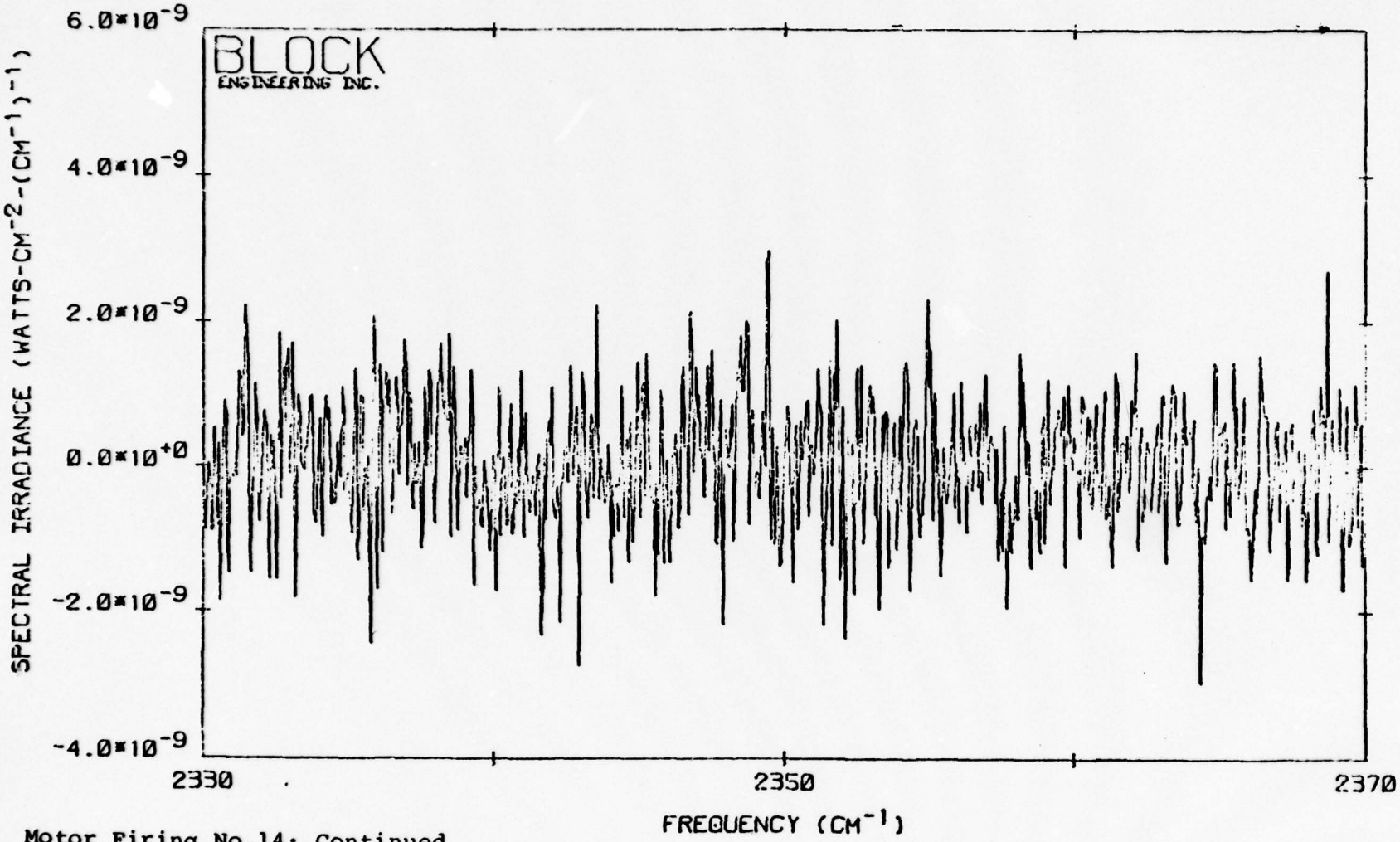
Motor Firing No.14; Continued



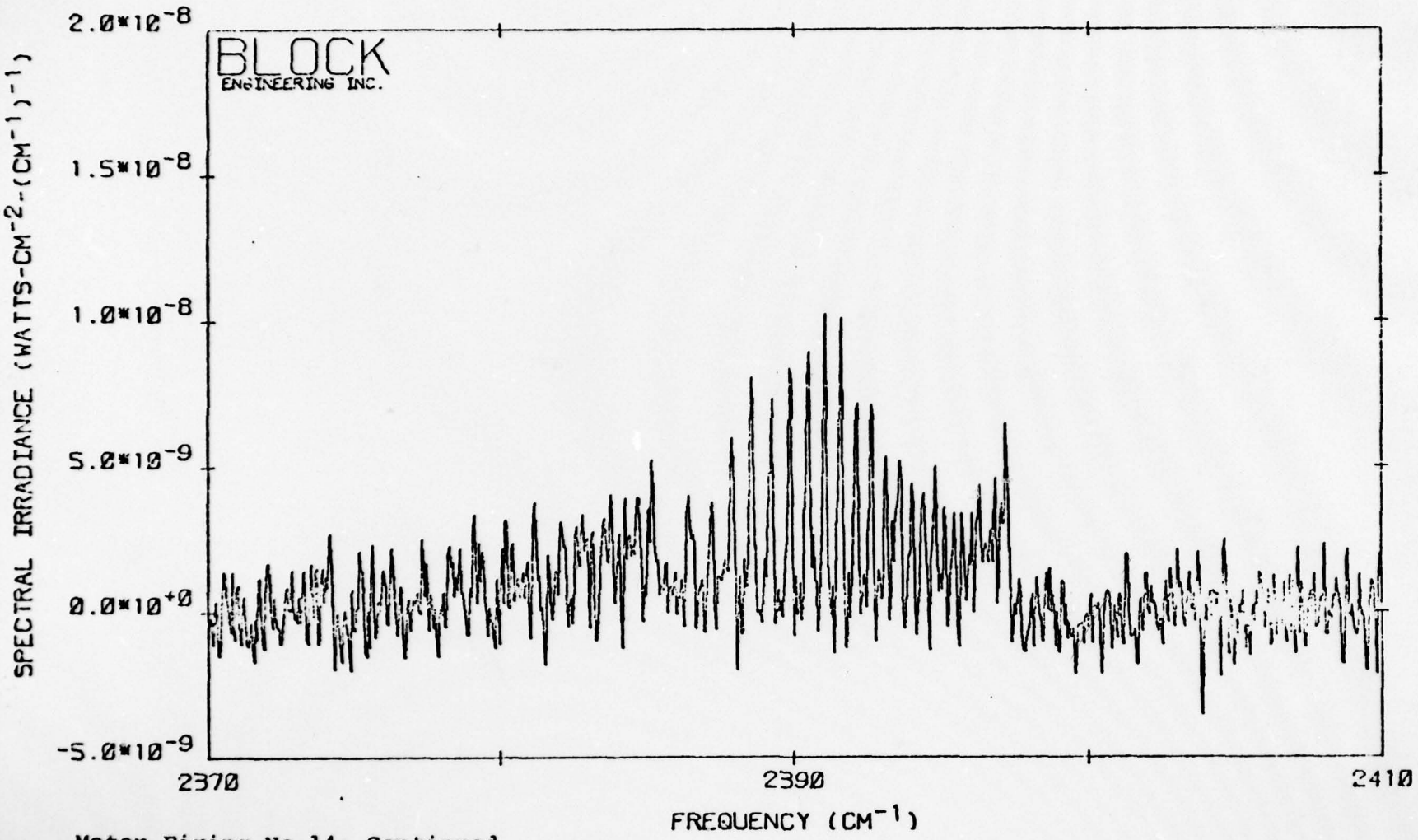
Motor Firing No.14; Continued



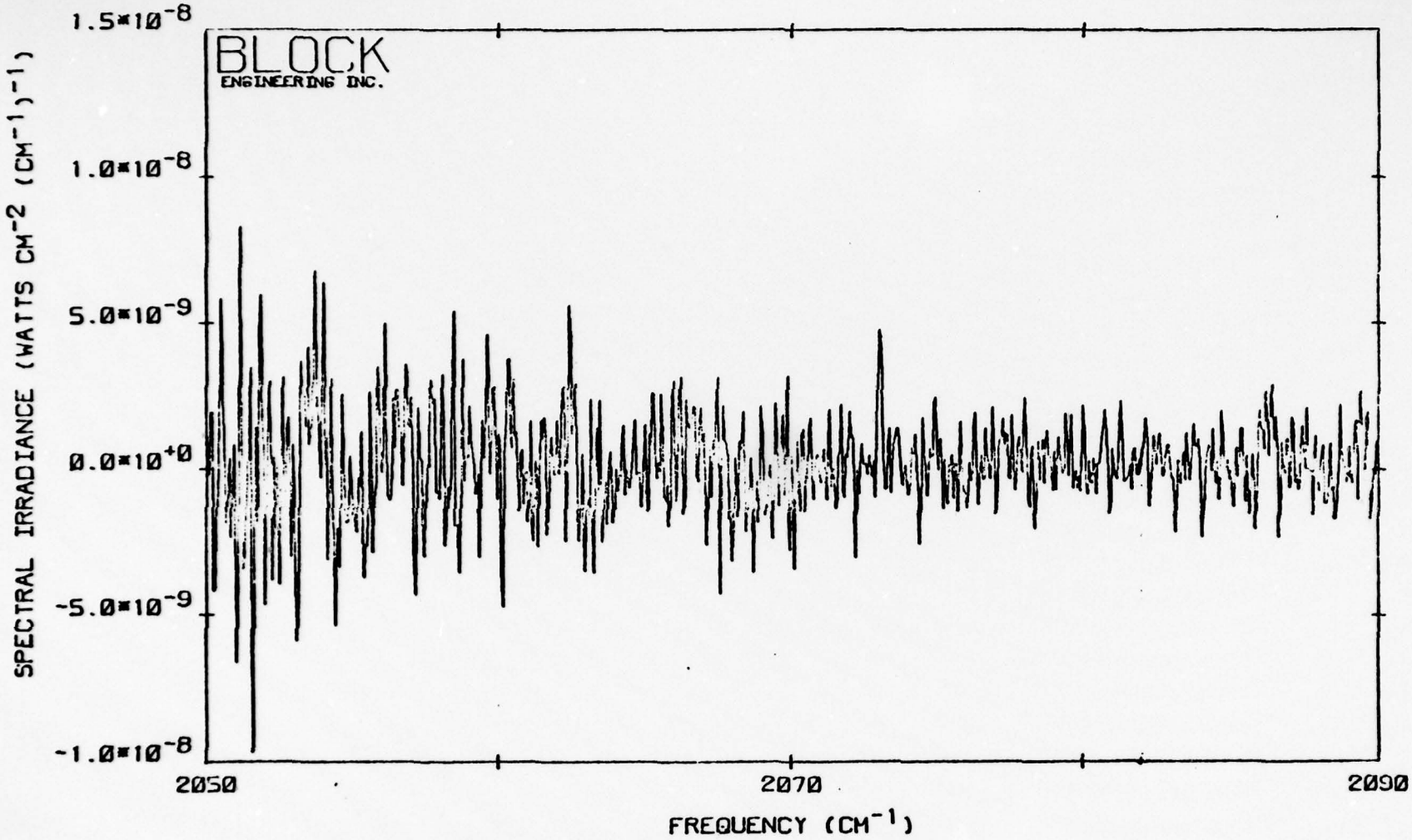
Motor Firing No.14; Continued



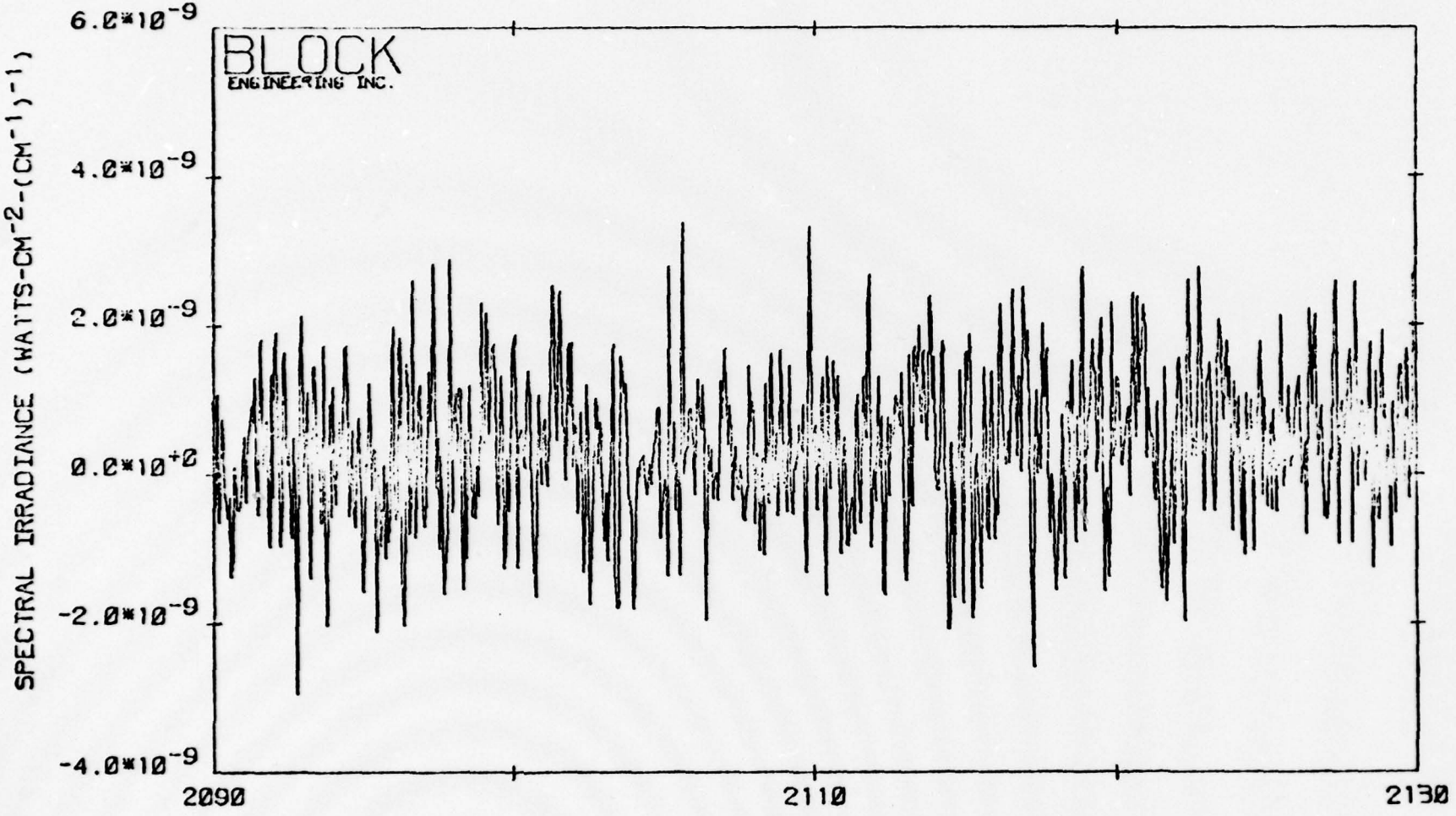
Motor Firing No.14; Continued



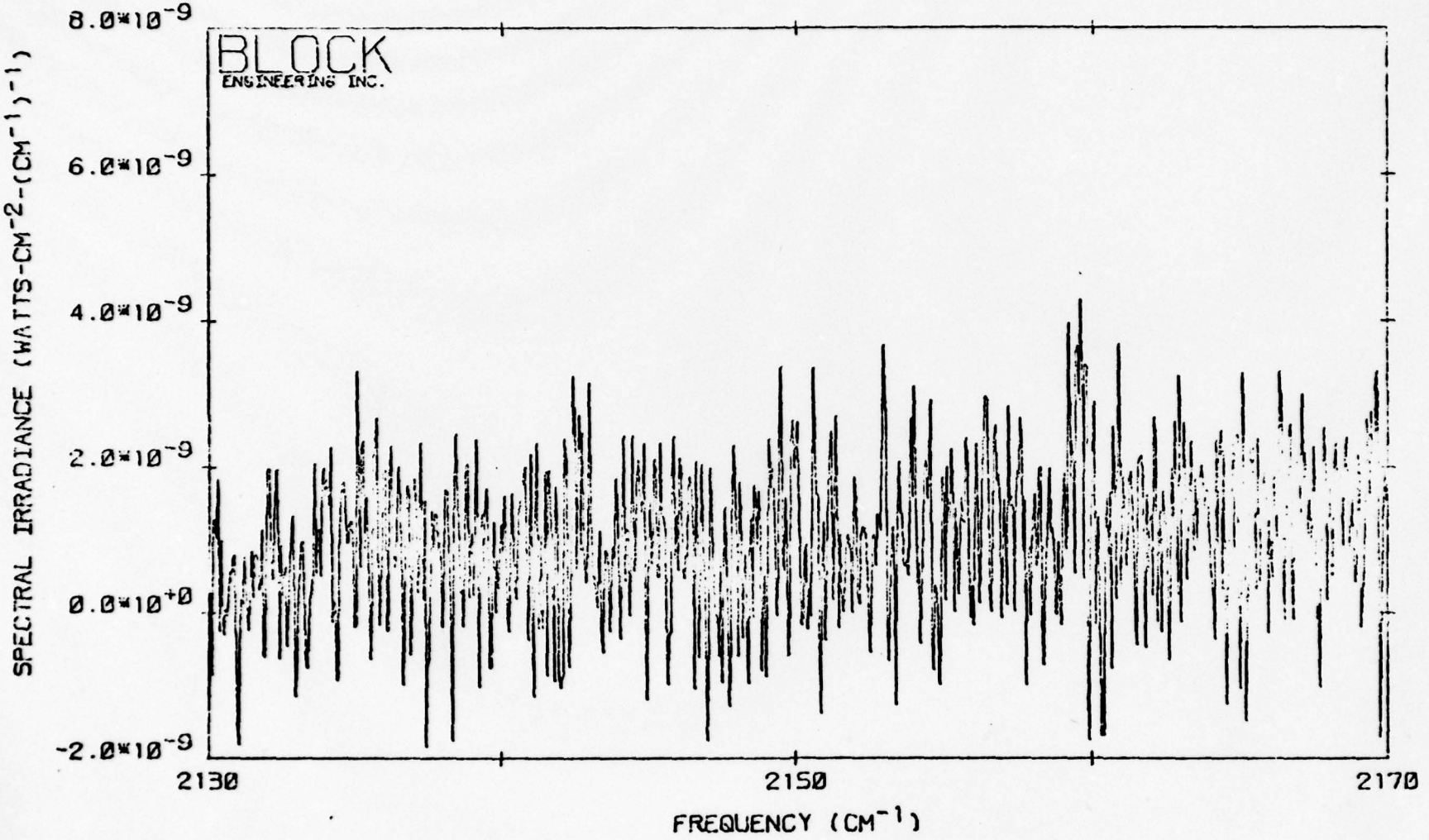
Motor Firing No.14; Continued



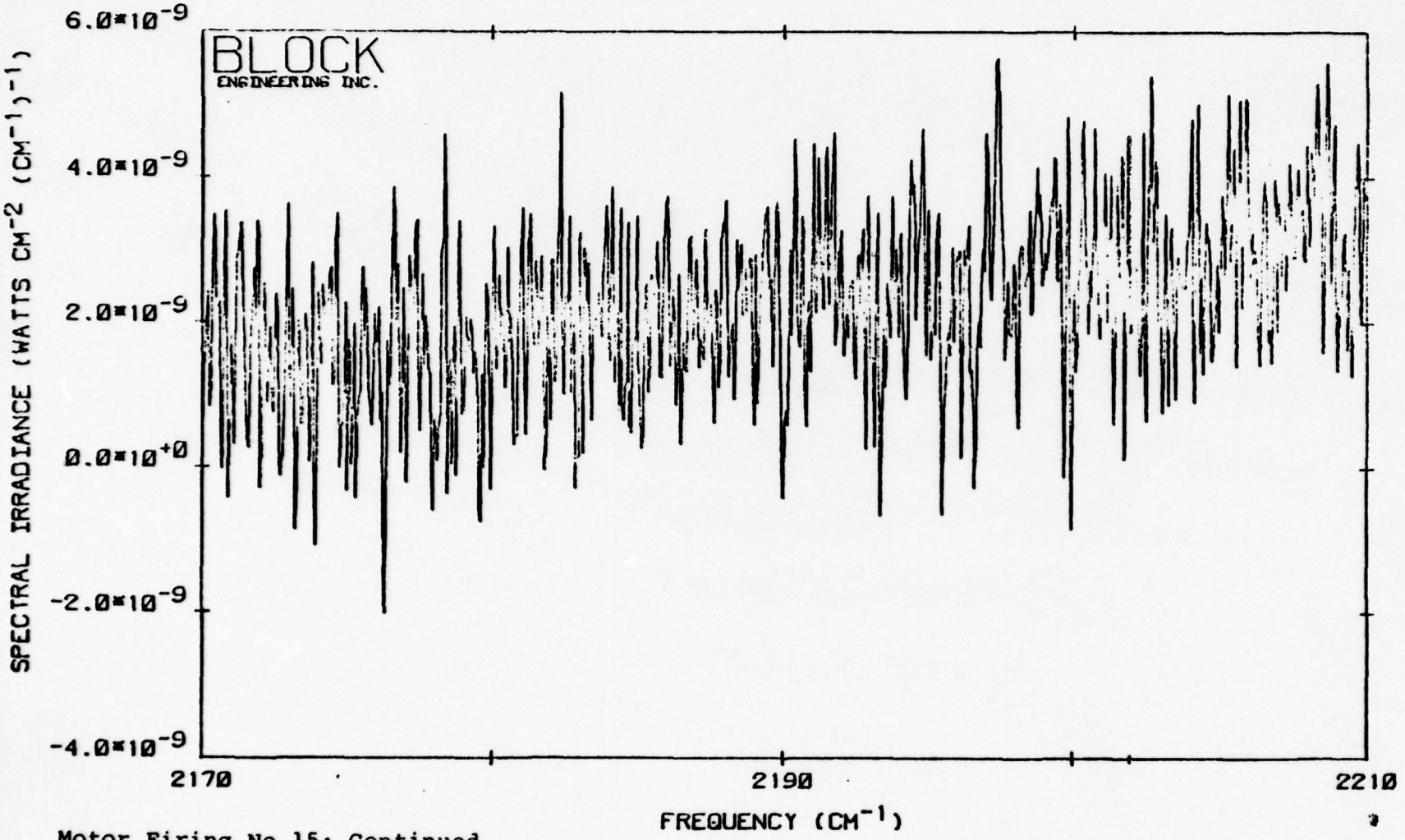
Motor Firing No.15; 12.19 km Altitude; 5 cm From Exit Plane



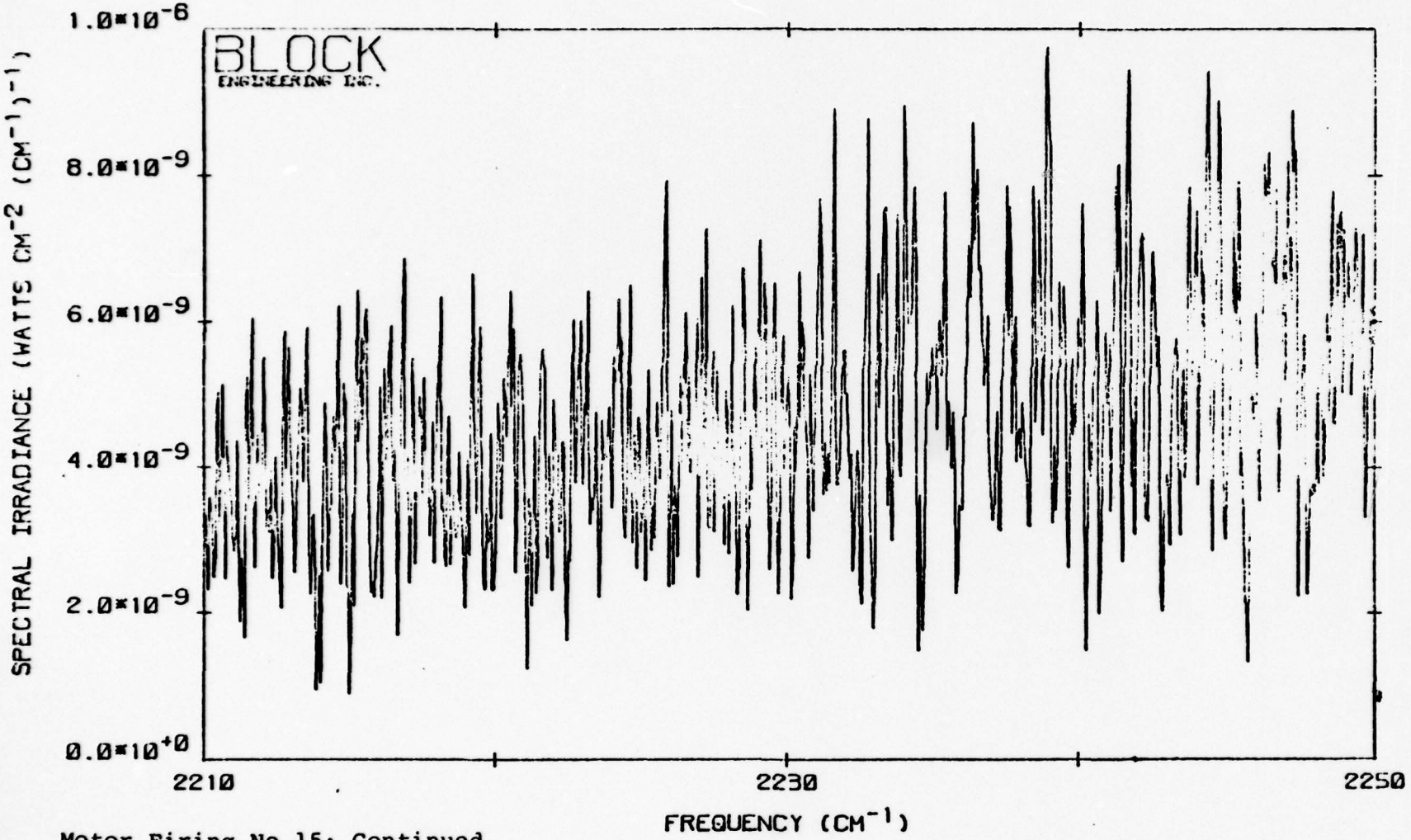
Motor Firing No.15; Continued



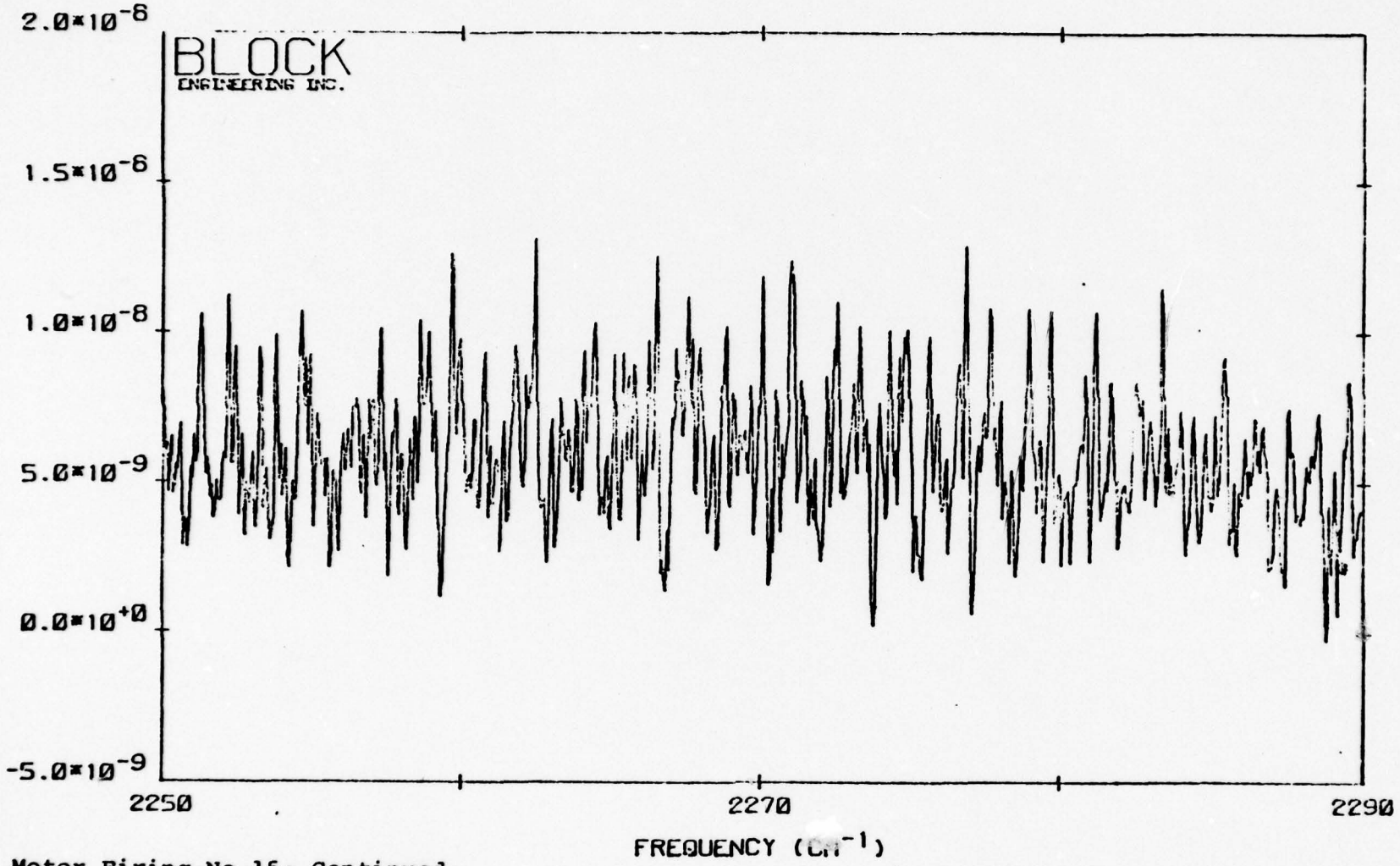
Motor Firing No.15; Continued



Motor Firing No.15; Continued



Motor Firing No.15; Continued



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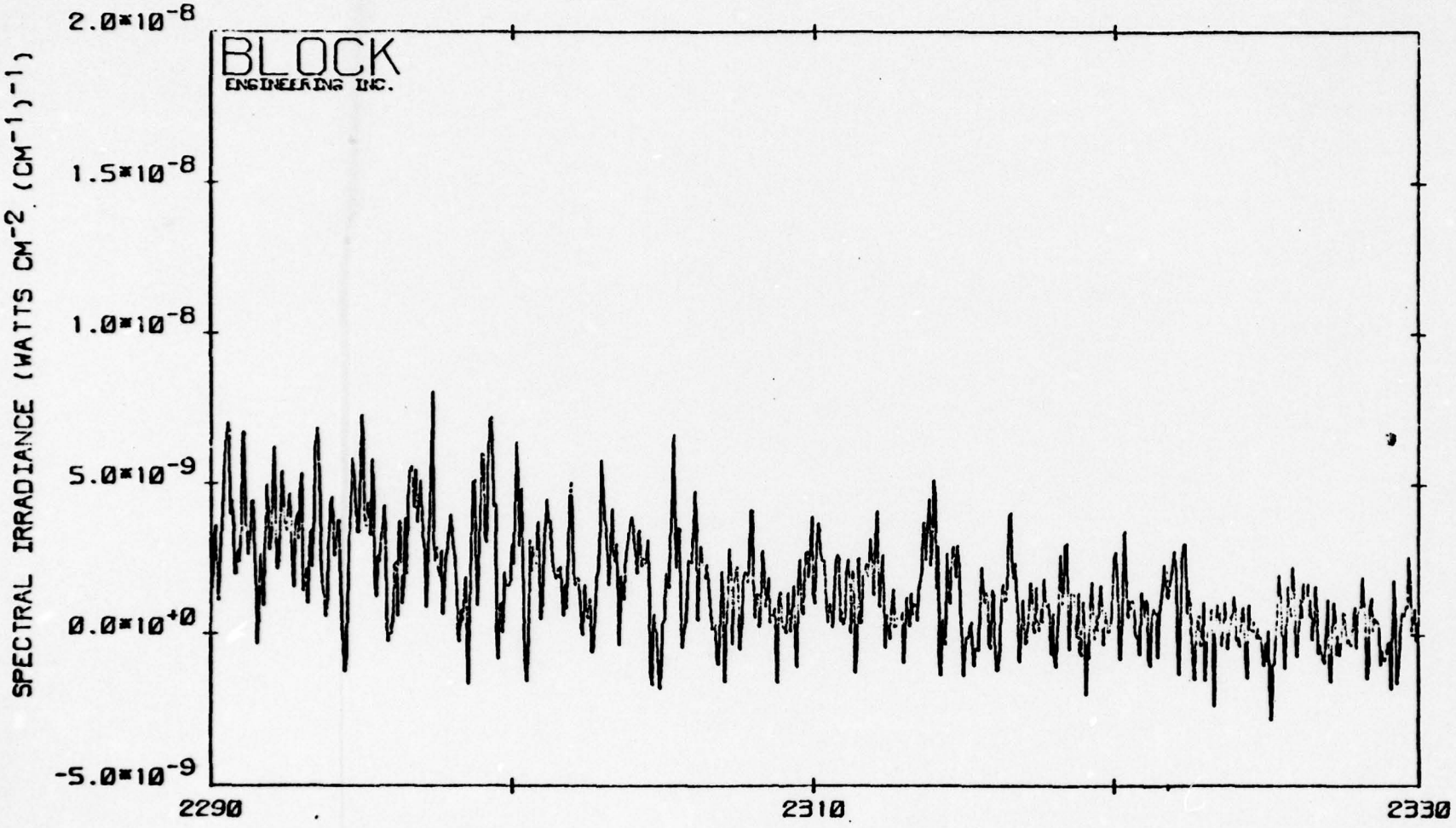

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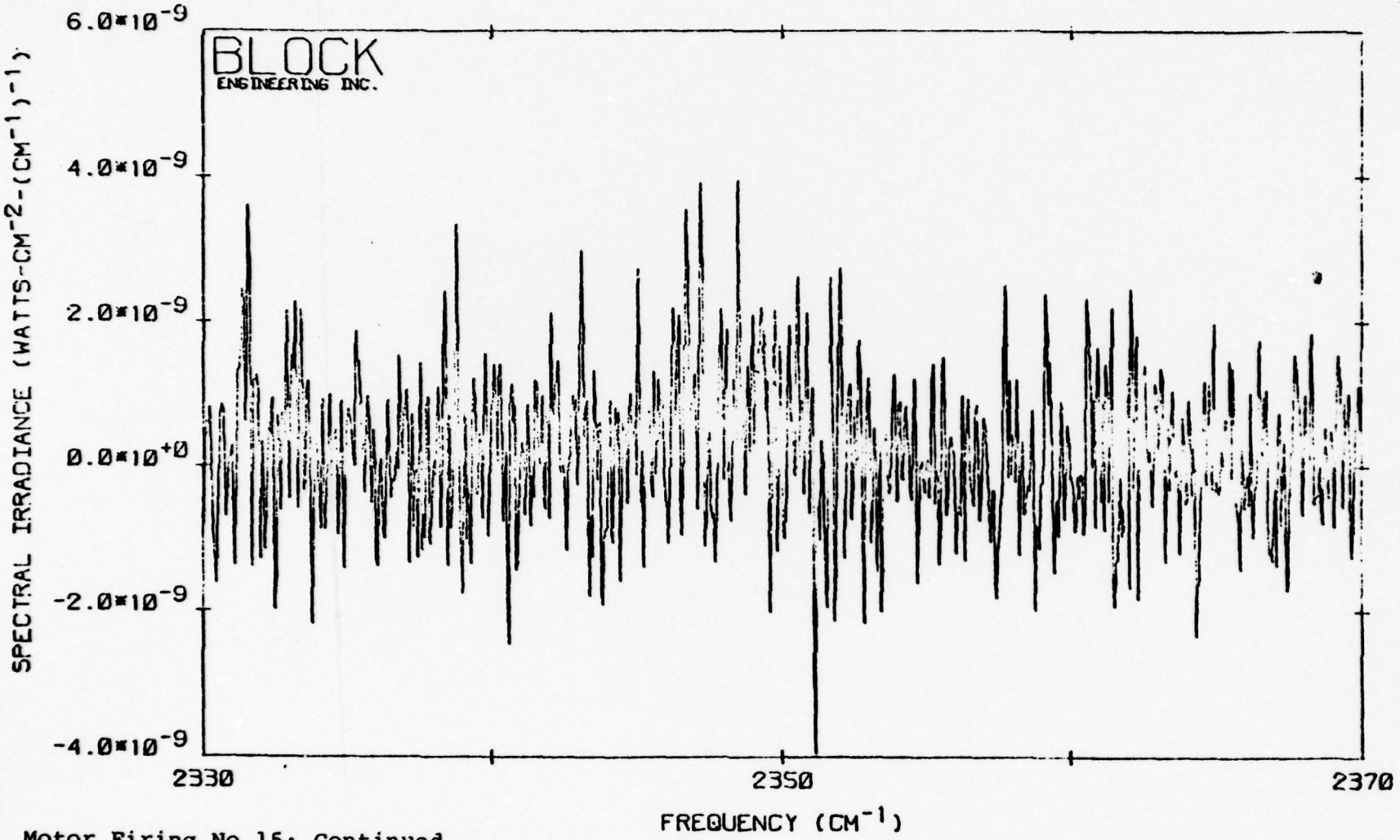

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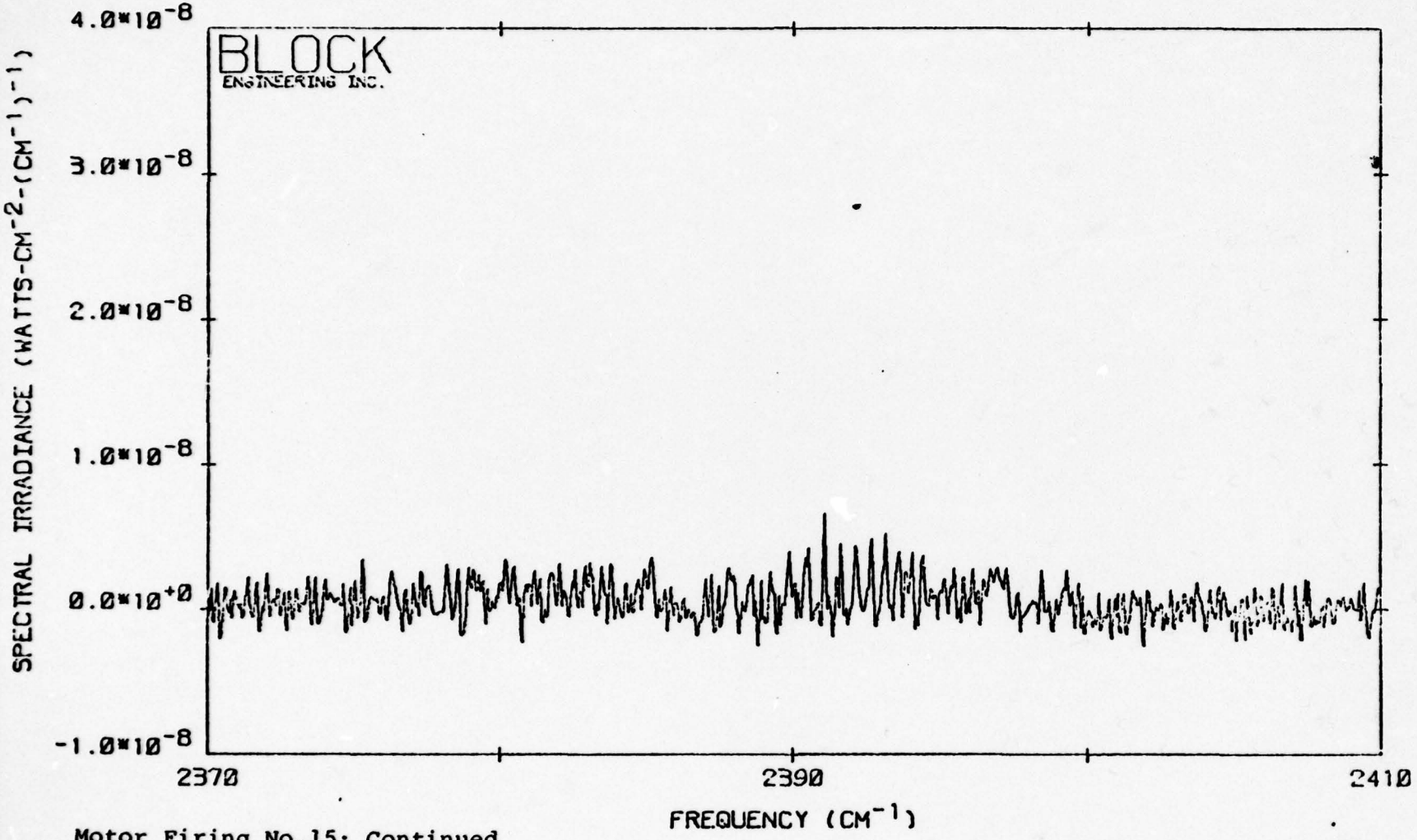

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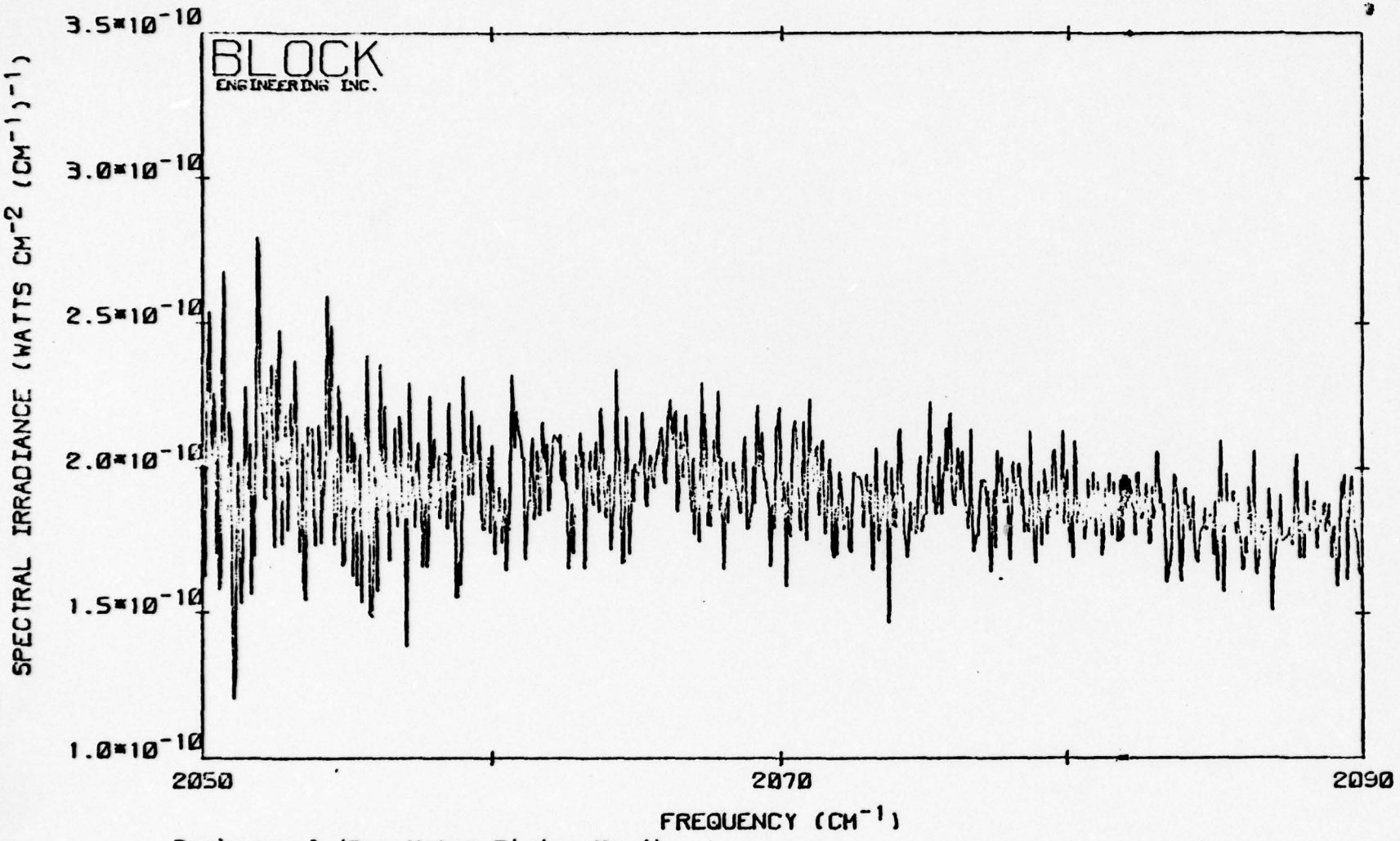
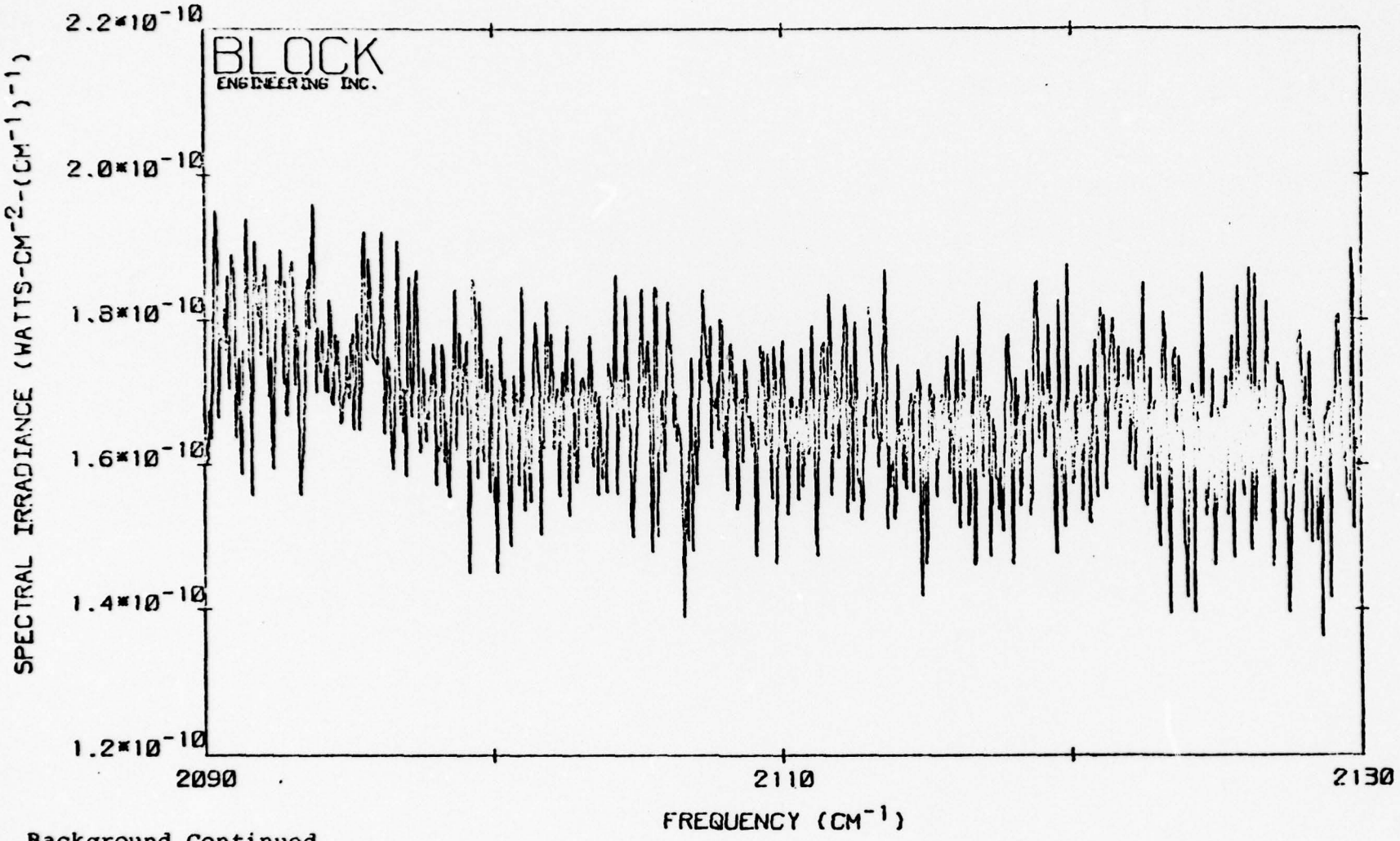


Background (Pre Motor Firing No.4)



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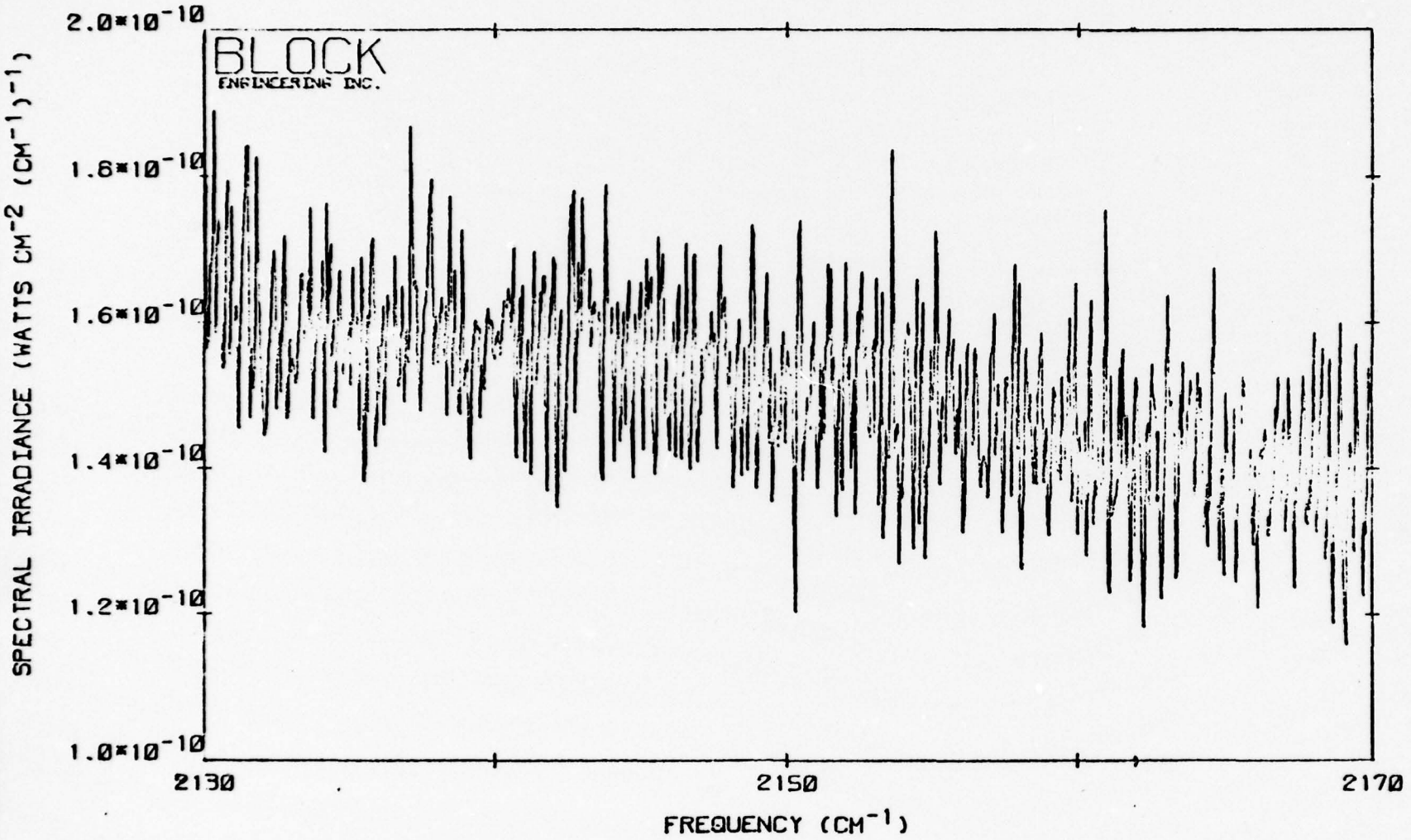

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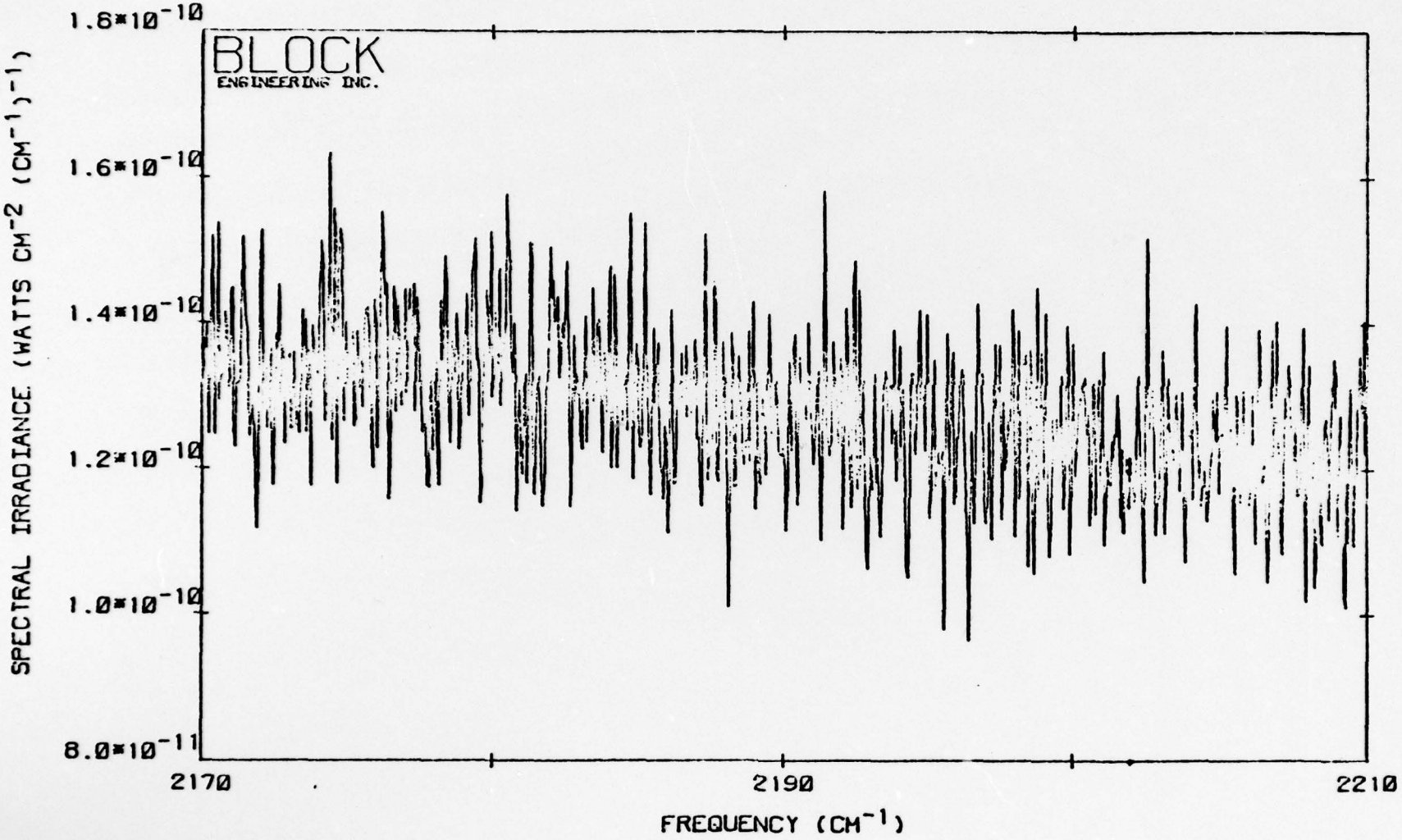

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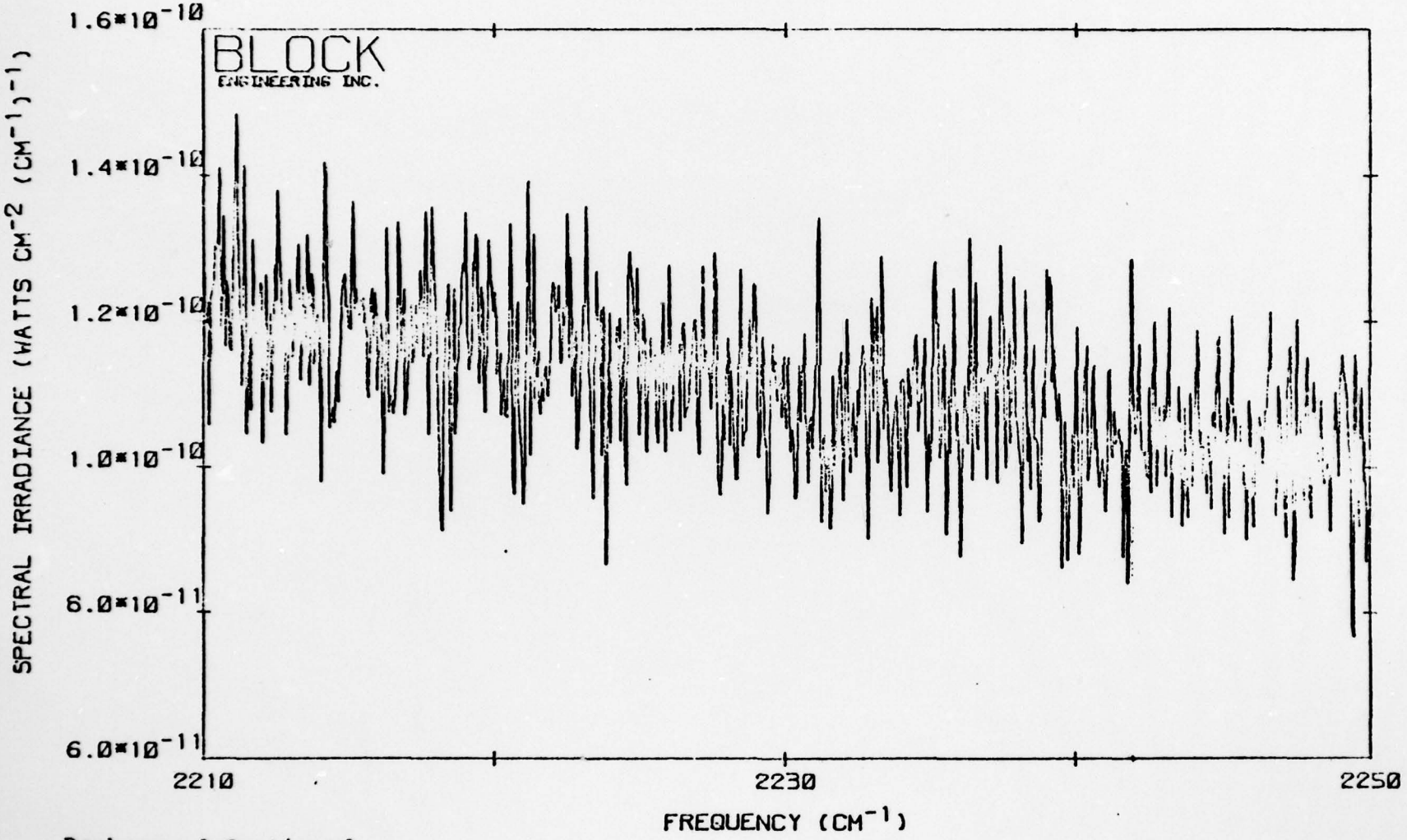

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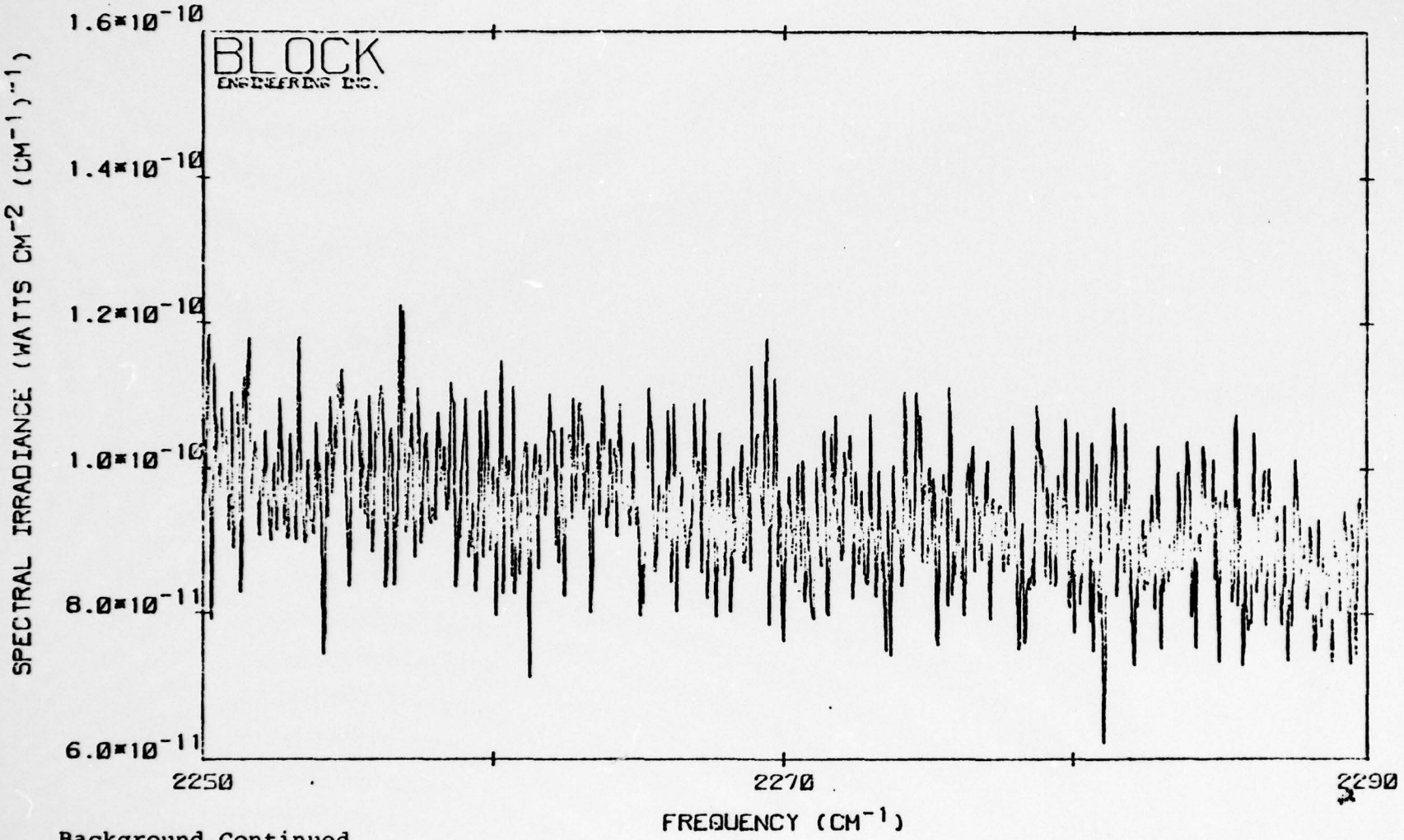

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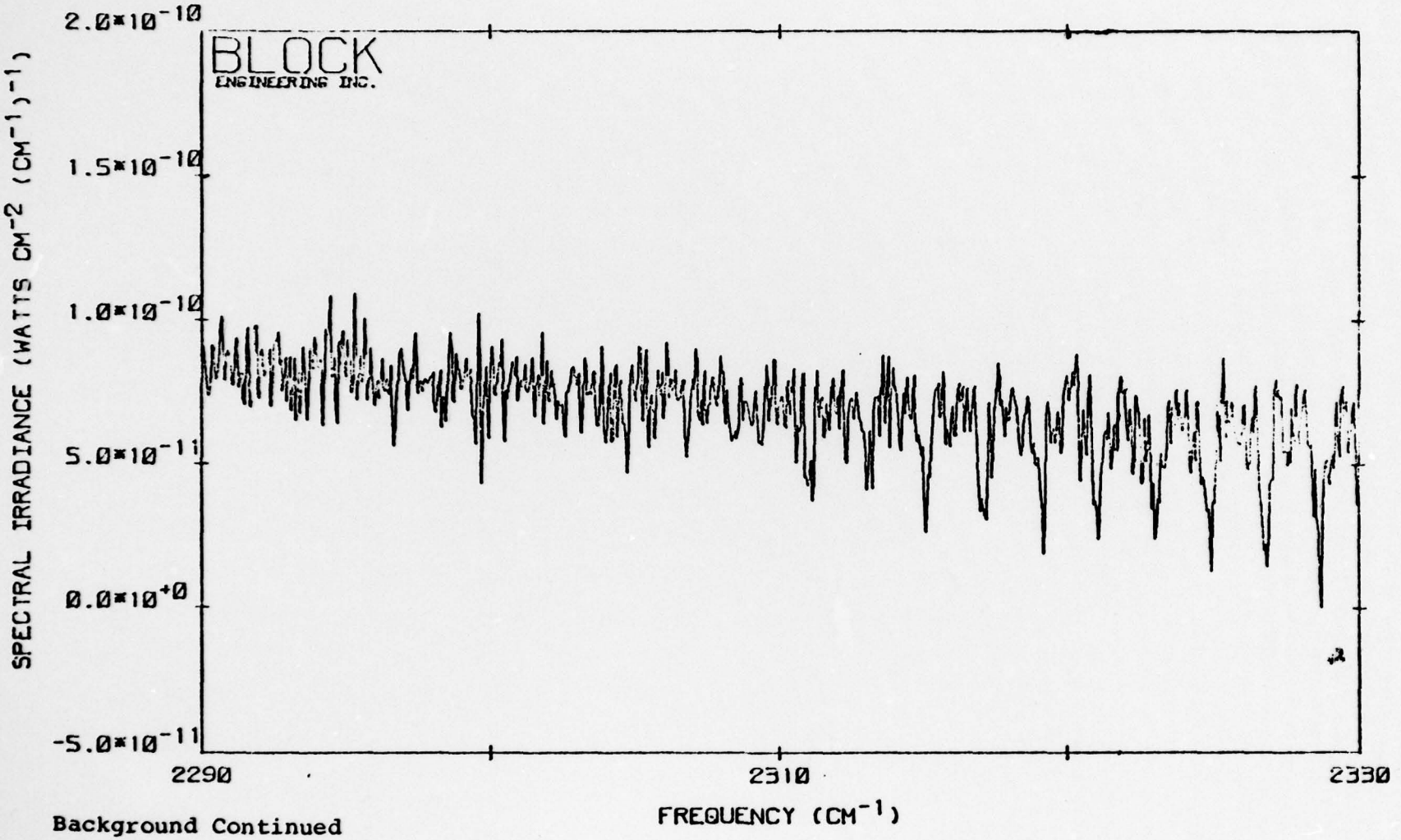

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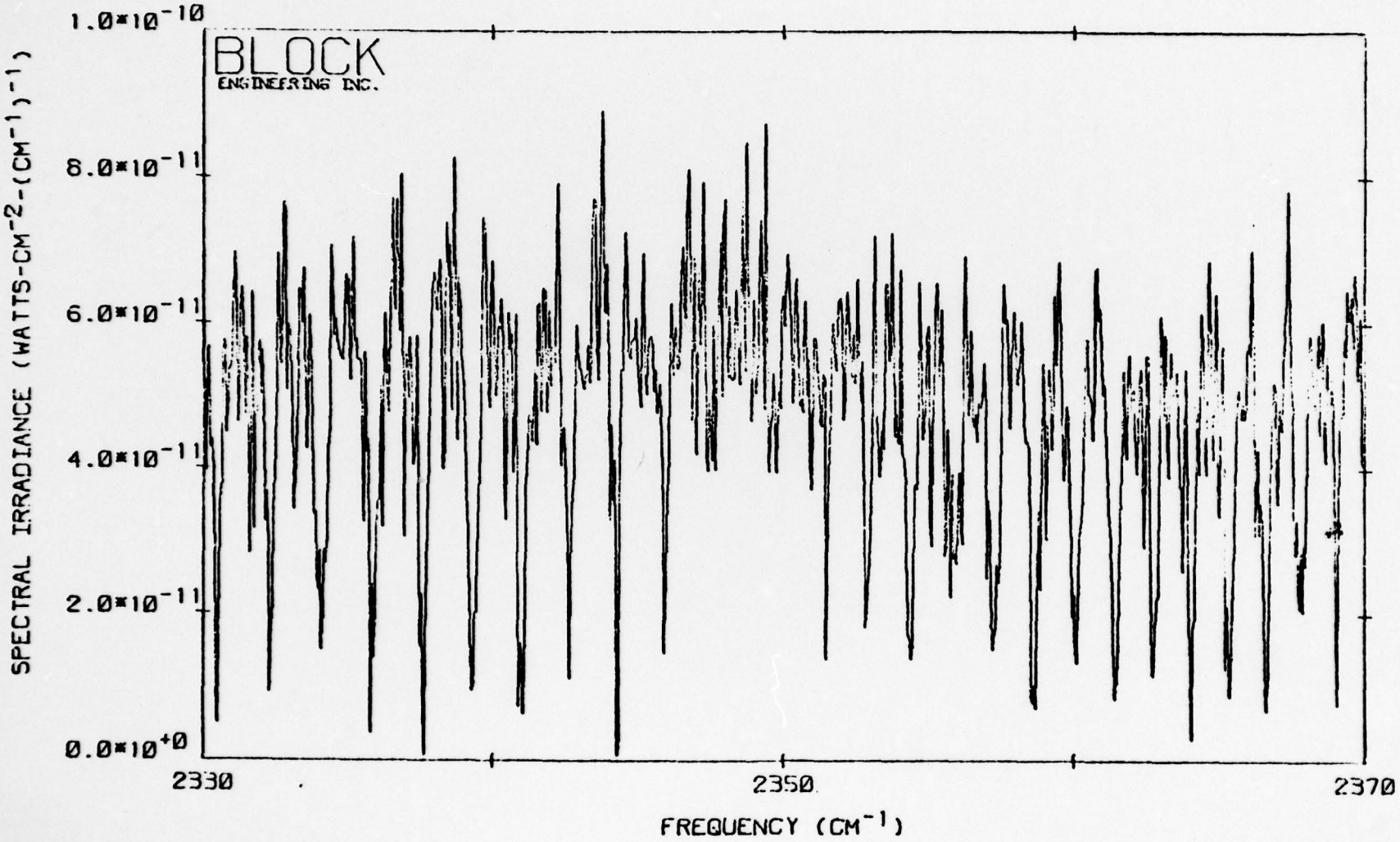

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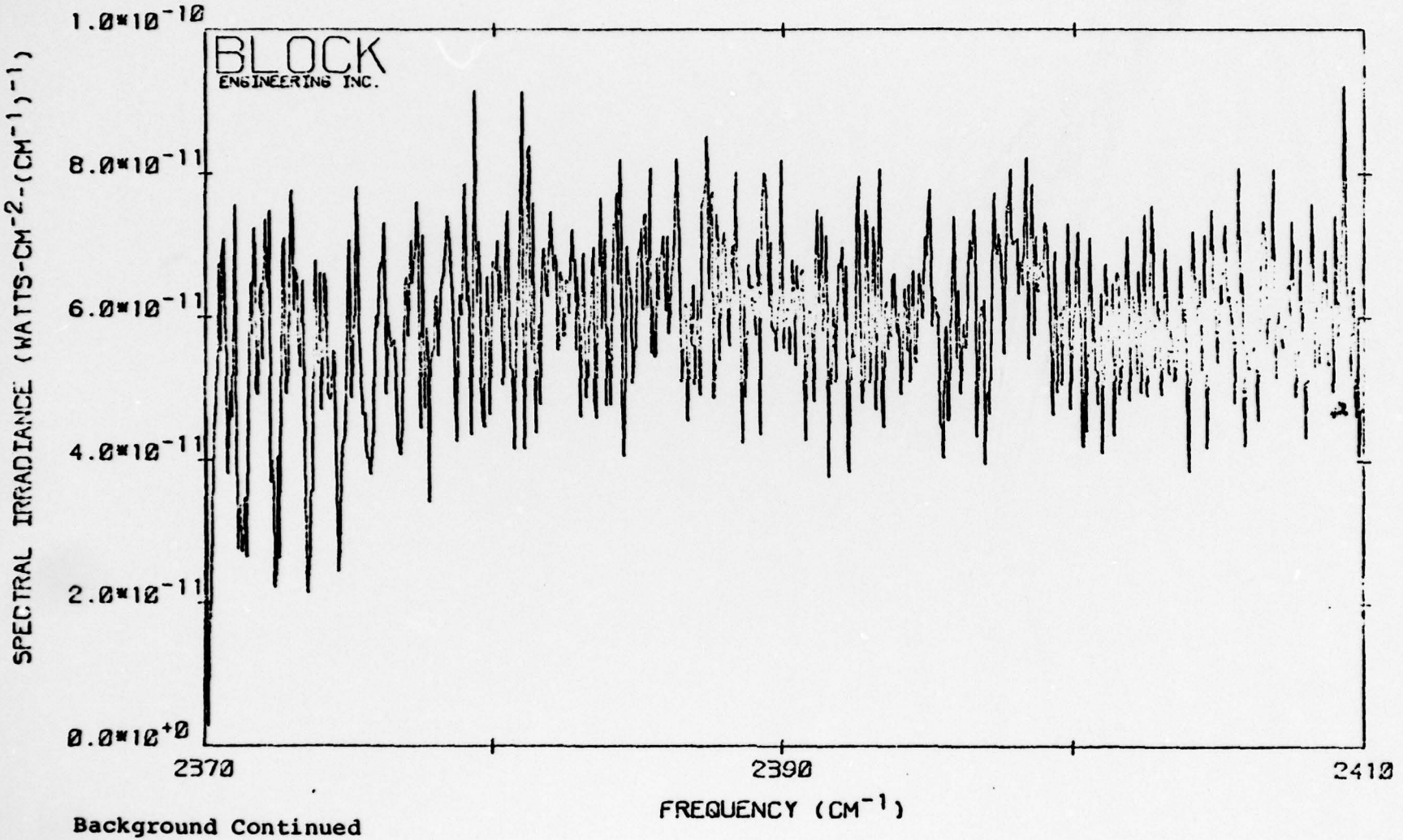

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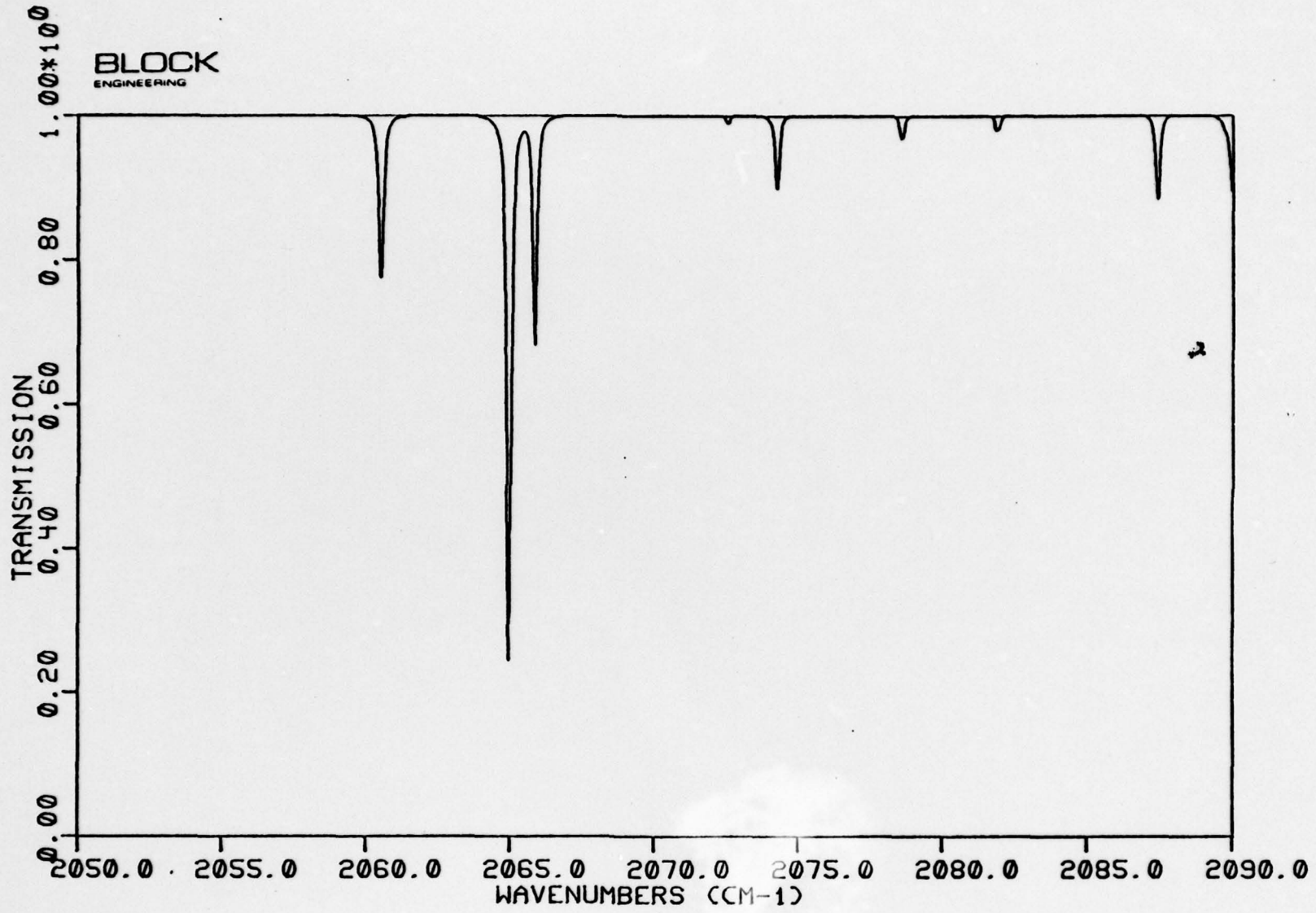
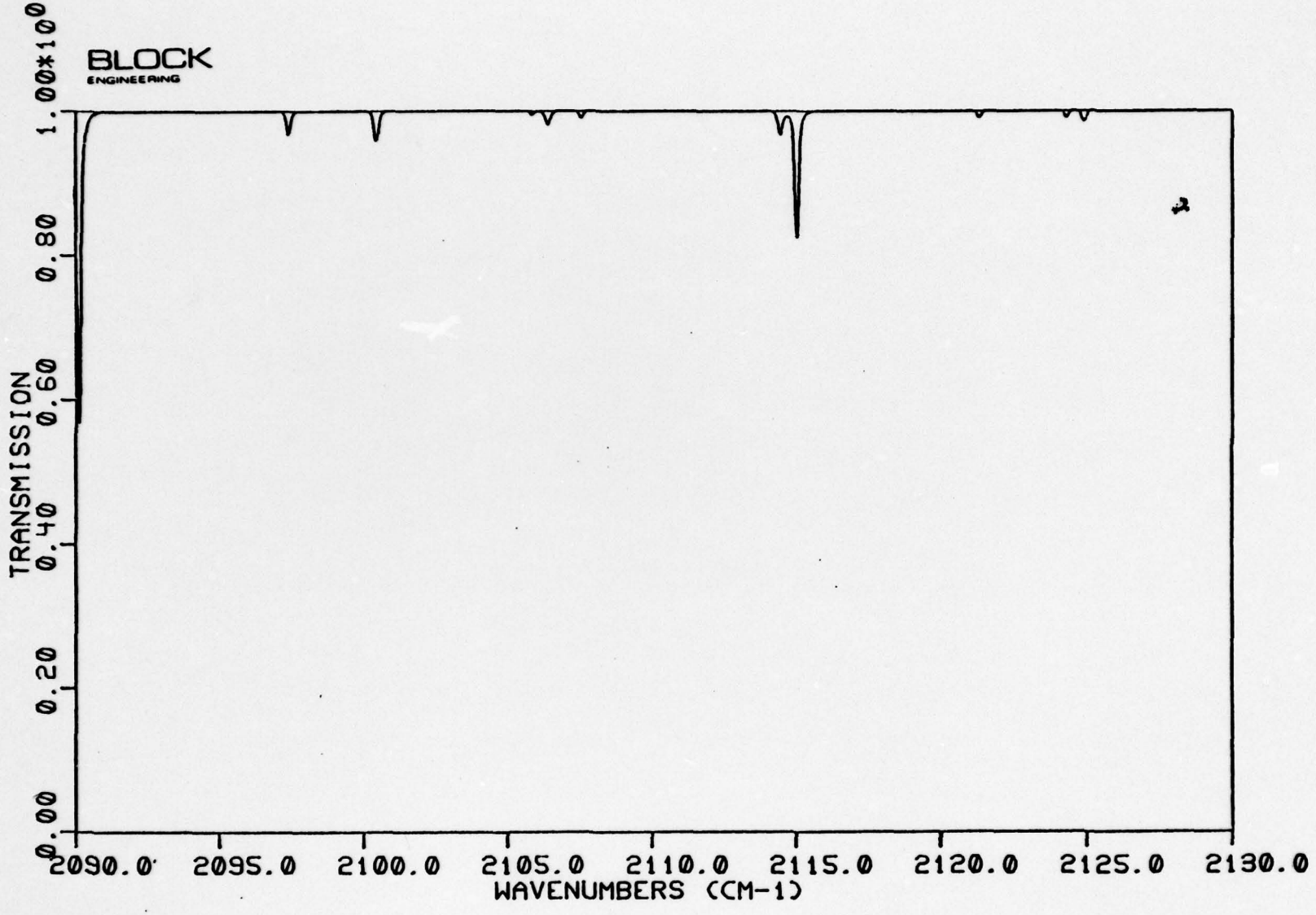


409 CM PATH

Calculated Atmospheric Transmission

TR1234B



409 CM PATH

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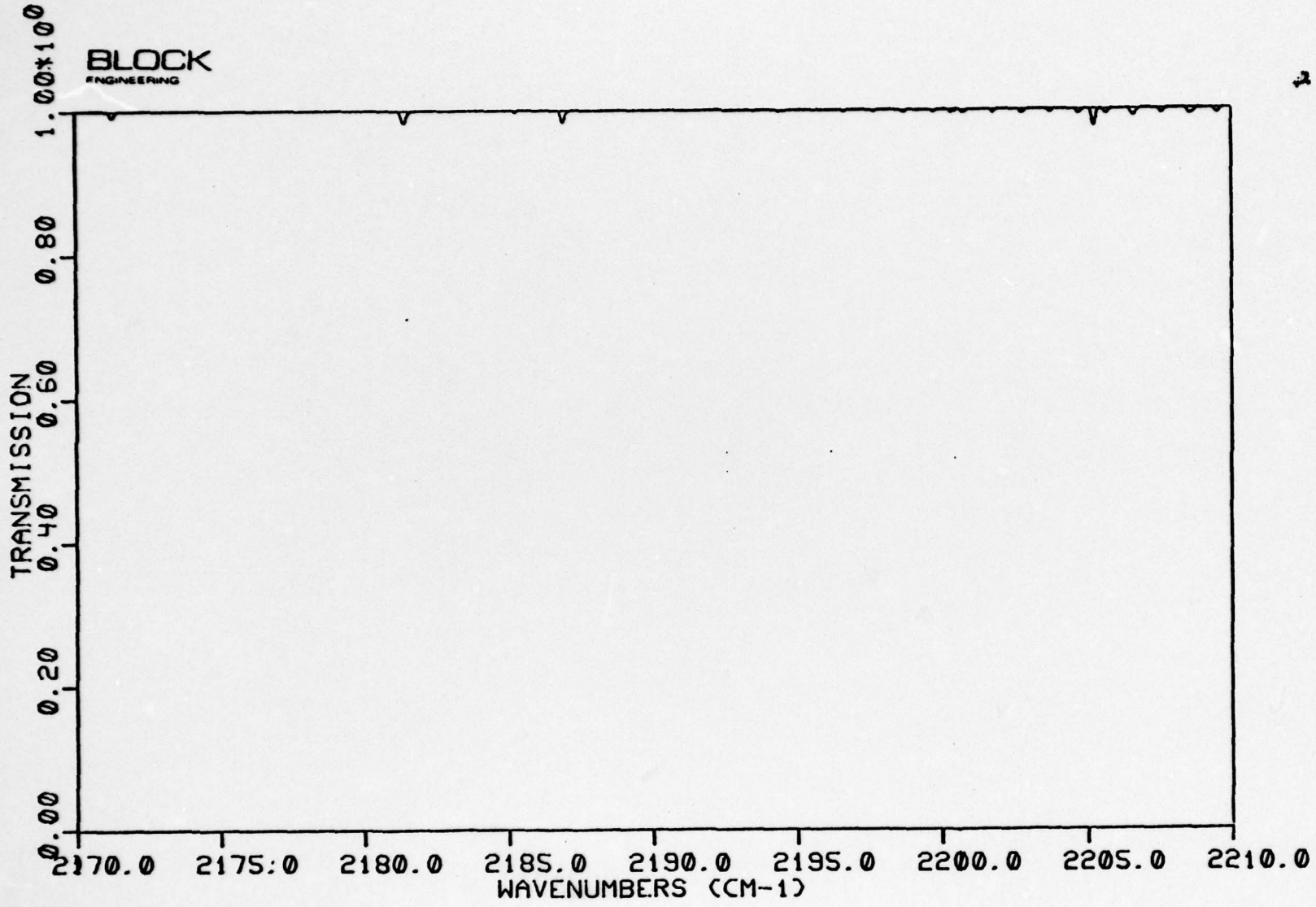

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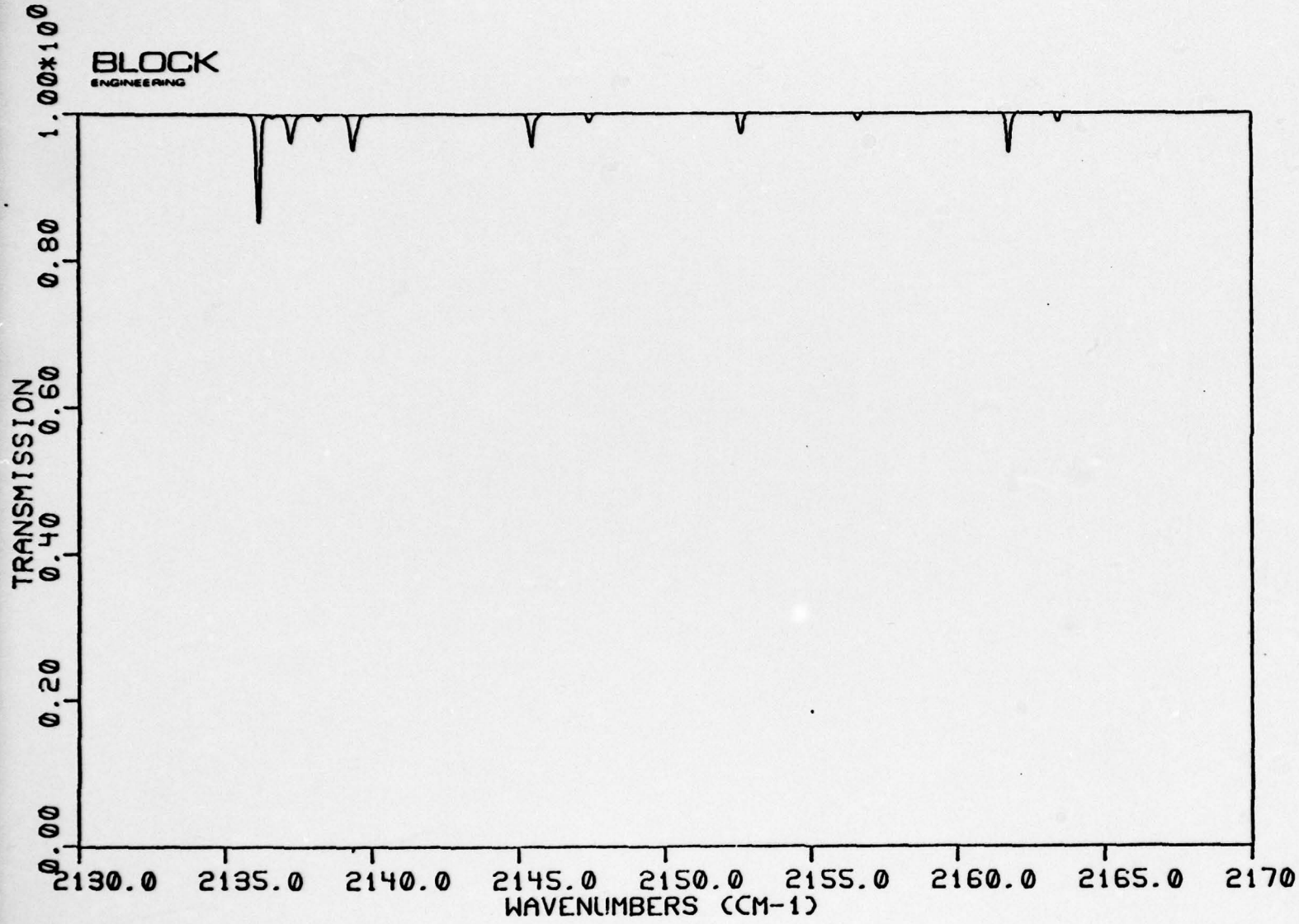

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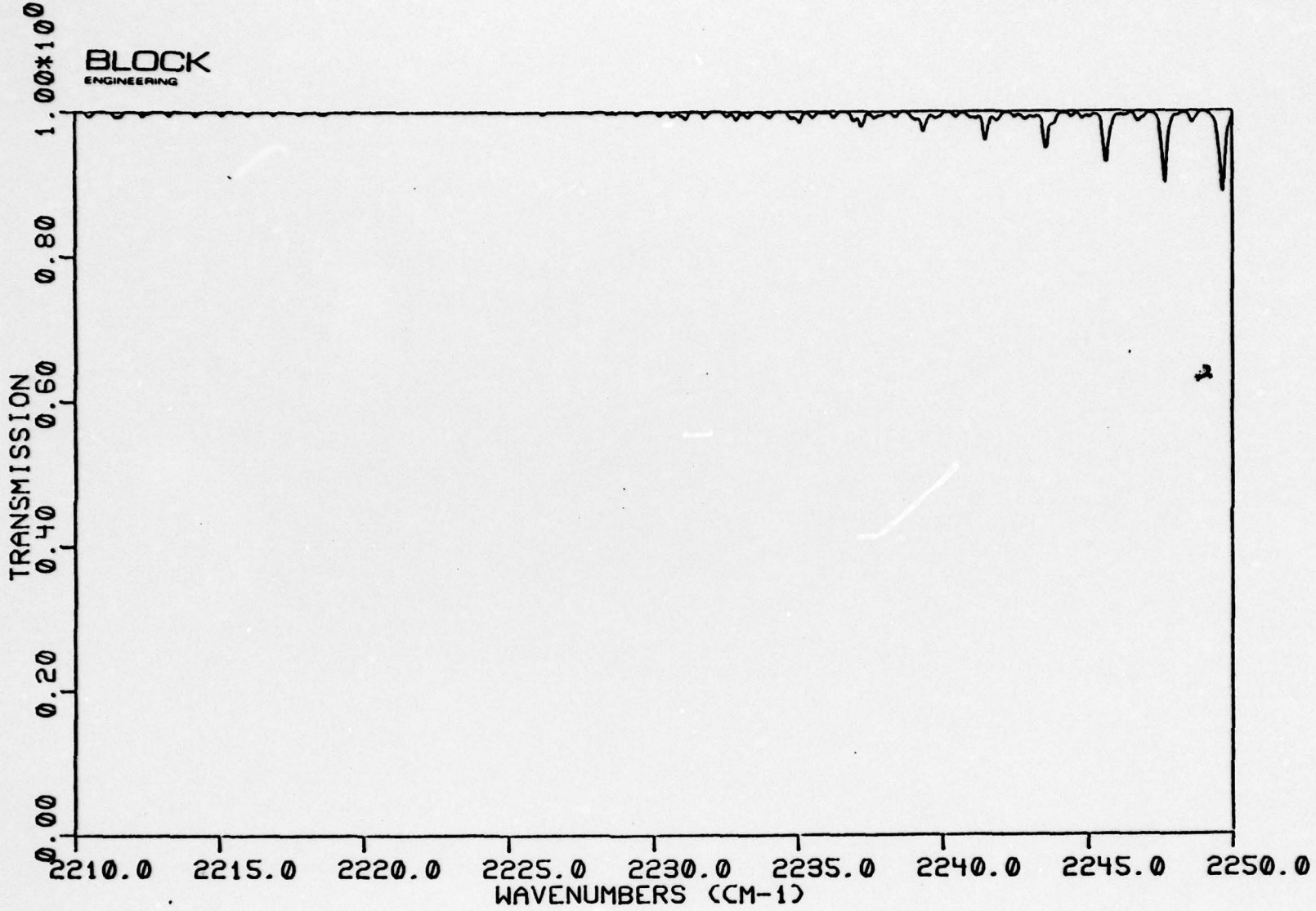

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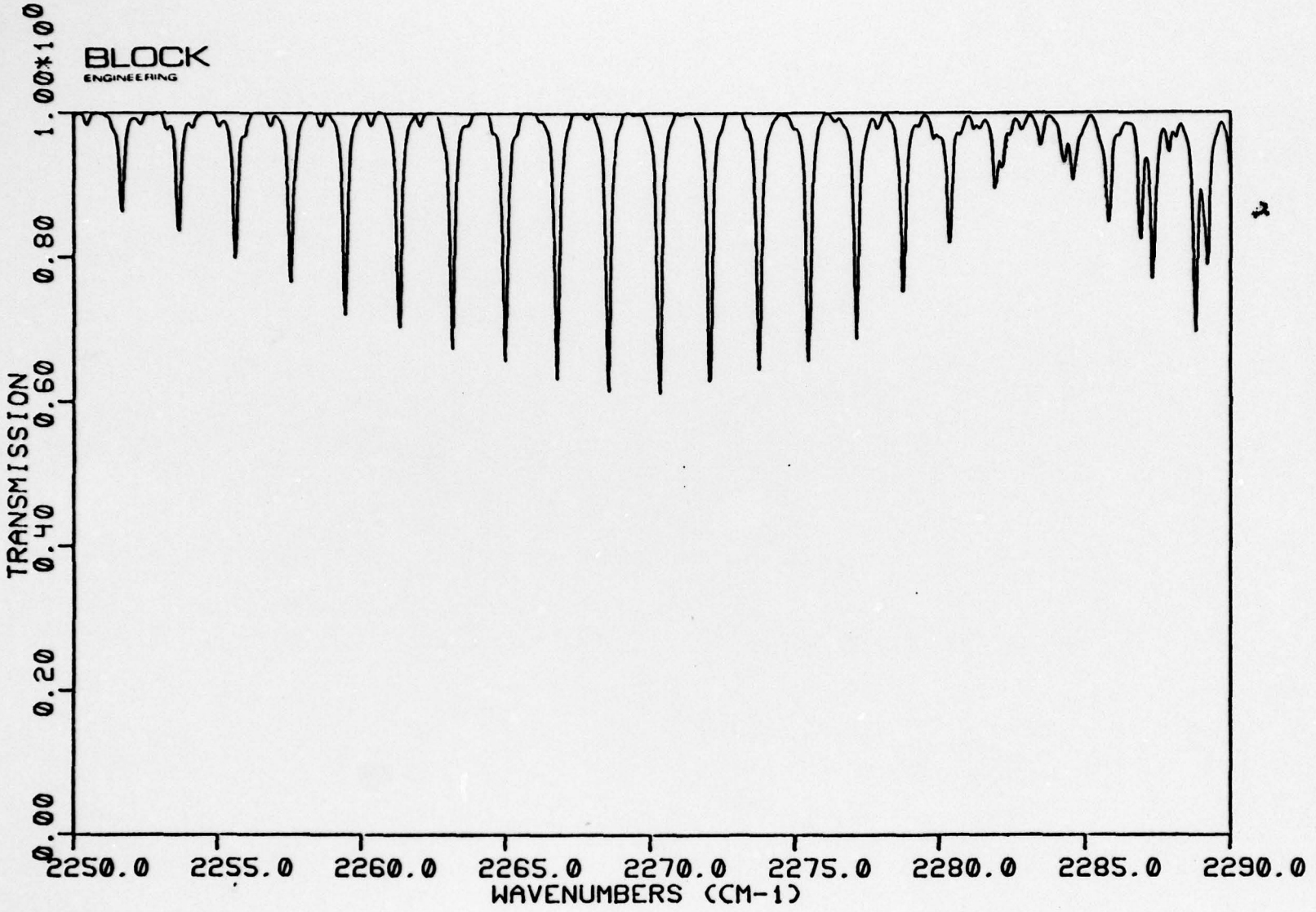
Calculated Atmospheric Transmission Continued

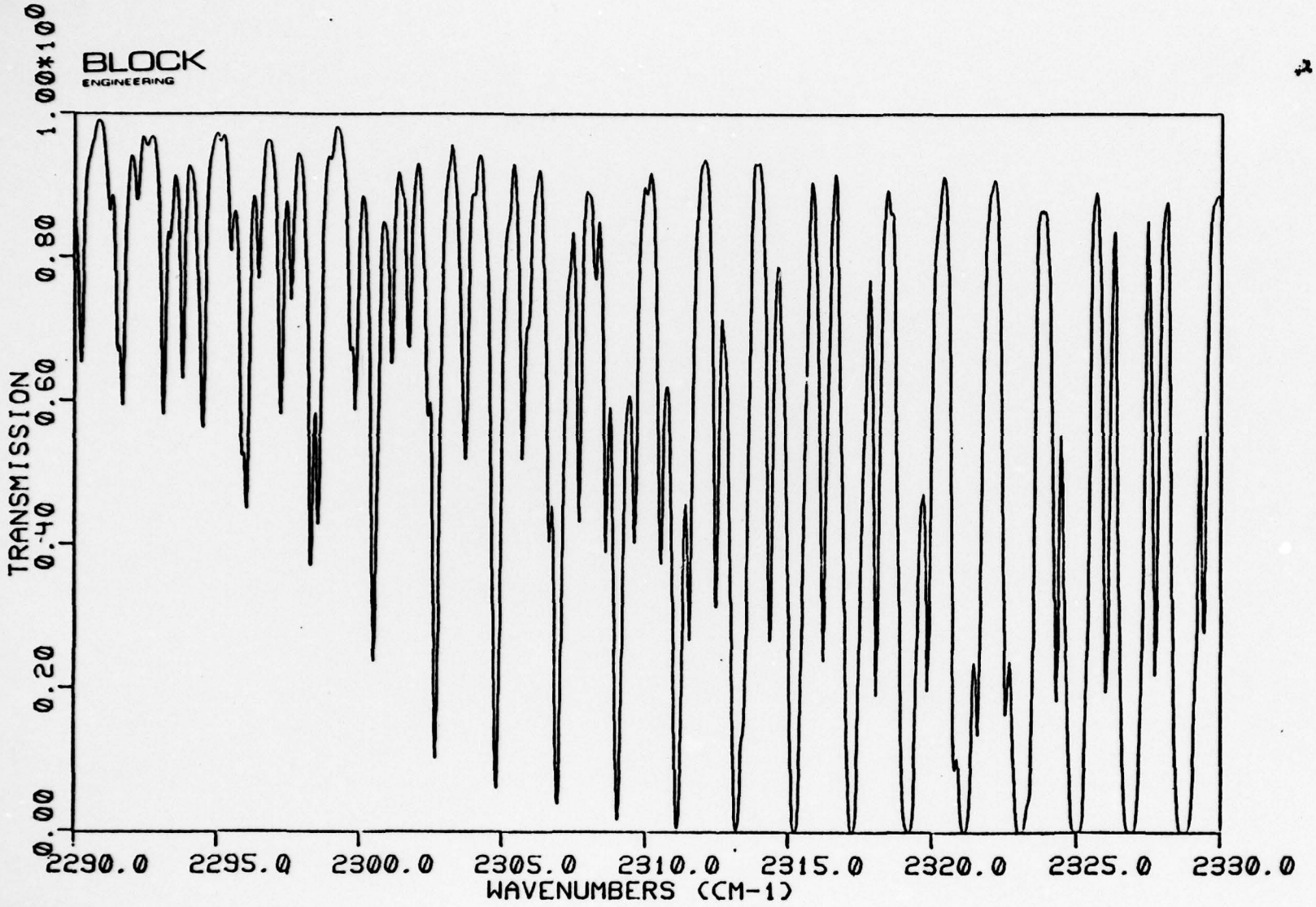
TR5B



409 CM PATH

Calculated Atmospheric Transmission Continued

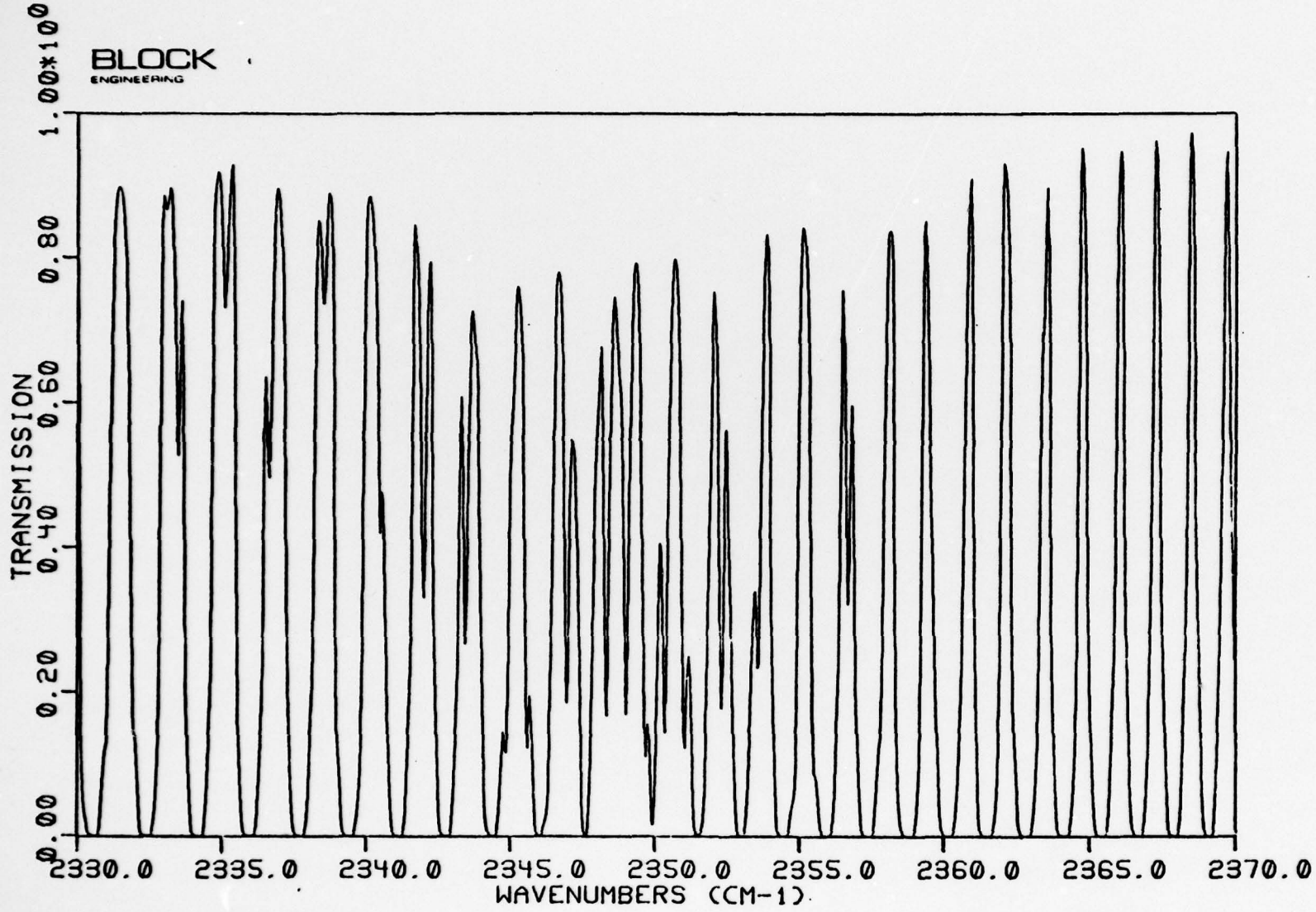
TR6A



409 CM PATH

Calculated Atmospheric Transmission Continued

TR7A



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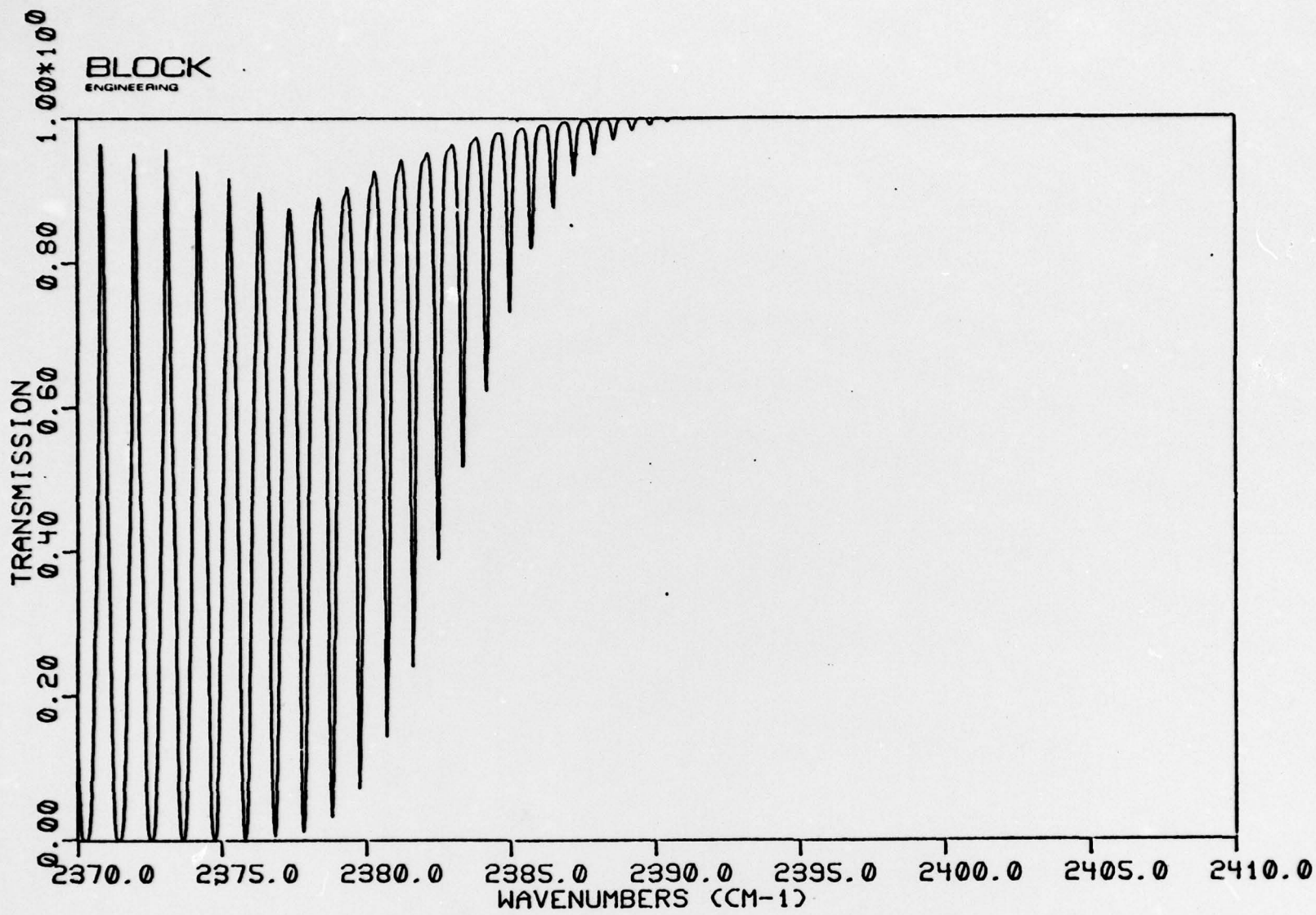
Calculated Atmospheric Transmission Continued



409 CM PATH

Calculated Atmospheric Transmission Continued

TR9A